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# Relative yields of mixtures and monocultures of oat genotypes evaluated across locations and years

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Relative yields of mixtures and monocultures of oat genotypes evaluated across locations and years

by

Ray Shorter

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# INTRODUCTION

Mixtures of field crops are grown extensively in primitive agriculture (Aiyer, 1949), but where contemporary agriculture is used monocultures are common. The commercial possibilities of heterogeneous populations produced by mixing different genotypes have received increased attention in recent years. The alleged advantages of heterogeneous populations over monocultures are (a) higher yield through more efficient utilization of environmental resources, (b) greater stability of performance across diverse environments, and (c) stable resistance to disease.

Several workers have shown that genotypic mixtures reduce losses from disease (reviewed by Browning and Frey, 1969). Some mixtures were more stable than their components grown in monocultures (Allard, 1961; Simmonds, 1962; Jensen, 1965) although certain monocultures may have greater stability than the most stable mixture in a given experiment. Of course, to justify the use of a genotypic mixture it should be superior in yield to its highest yielding component in monoculture, and this superiority should be repeatable acrcss environments.

The objectives of my study were to examine in oats (*Avena sativa* L.):

1. Yields of genotypic mixtures relative to those of their components in monoculture, i.e., relative mixture yield,

2. The effect of type of component, i.e., commercial cultivars or random lines, on relative mixture yield,
3. Repeatability of relative mixture yield across environments,
4. The effect of component frequency on mixture yield, and
5. Methods of identifying genotypes with good mixing ability.

# REVIEW OF LITERATURE

Trenbath (1974) reviewed numerous experiments involving the biomass productivity of mixtures in grasses, legumes, and cereals. Of 344 mixtures, 62.8% had biomass yields within the range of the component monoculture yields, 39.8% were below, and 60.2% were above the midcomponent pure stand mean. However, of 83 mixtures with biomass yields above that of the higher yielding component, only three were significantly higher yielding.

Yields of mixtures in cross-pollinated species, or between $F_1$ hybrids, generally have been similar to the mean monoculture yields of their components. Stringfield (1959) examined 42 two-component mixtures of corn hybrids, both single and double crosses, and found that mixture yields were similar to the mean yields of the contributing hybrids grown separately. Eberhart et al. (1964) found the average performance over two locations of any pair of maize single crosses grown in mixed stands was similar to their mean performance in pure stands. Generally, a yield increase in one component was matched by a yield decrease of the other. Kannenberg and Hunter (1972) observed no differences between the yields of binary mixtures of 10 maize hybrids and those of their midcomponent means. In sorghum, Ross (1965) found only 2 of 50 cases where blends of single cross hybrids differed significantly from their midcomponent means for grain yield.

However, Reich and Atkins (1970) reported that across nine environments, 22 of 32 sorghum blends of parental lines or $F_1$ hybrids exceeded the mean of their components for yield. Six outyielded their more productive component. Doney et al. (1965) noted increased tuber production in two-component mixtures of potatoes compared with the yields from monocultures.

Often mixtures in self-pollinated crops have shown a slight advantage in grain yield over the mean of the components in pure stand, but rarely has a mixture outyielded its highest yielding component. Early experiments with soybeans (Mumaw and Weber, 1957; Probst, 1957) indicated that mixtures, in general, performed slightly better than the appropriately weighted mean of the components, but no better than the high components. For three soybean mixtures, Hinson and Hanson (1962) reported no significant difference between the yield of the mixture and that of its components grown in pure stand. However, in 10 two- and three-line mixtures of four soybean lines, Brim and Schutz (1968) found that all mixtures exceeded the component mean for yield. Seven mixtures were superior, although not significantly, to the best component of the respective mixtures. Allard (1961) reported that four two-component mixtures of three lima bean genotypes yielded slightly less than the means of the components in pure stand and substantially less than the highest yielding components.

Jensen (1952) and Simmonds (1962) reviewed much of the early work with mixtures in cereals. Intergeneric mixtures of wheat, oats, and barley outyielded the means of their components by 3-9%, with individual mixtures showing up to 23% superiority (Jensen, 1952). Intraspecific mixtures of randomly chosen good local varieties of wheat, oats, or barley exceeded the component means by 3-5% for grain yield (Simmonds, 1962). Nuding (1936, cited by Simmonds, 1962) found that for grain yield six 1:1 mixtures of four wheat varieties exceeded their midcomponent means by up to 3% when evaluated across seven sites for three years. Frankel (1939) reported that in blends of a standard wheat variety with each of 11 breeding lines in New Zealand the blends were not significantly different from the midcomponents for grain yield. Allard and Adams (1969) tested mixtures of four wheat varieties for two years in California. Averaged over all mixtures in which the components occurred in a frequency of 1:1, the mean yield of the four varieties in mixtures was 1.3% above their mean yield in pure stand. The maximum increase for individual varieties was 2.4%. In a 1:1 mixture of two wheat varieties, Khalifa and Qualset (1974) found the mixture exceeded the midcomponent by 1% for grain yield.

Gustafsson (1953) reported that in three 1:1 mixtures of barley genotypes, mixture yields exceeded the midcomponent yields by up to 2.4%. In mixtures between parents or $F_{38}$ derived lines from composite cross II of barley, Sammeta (1967) found the mean yield of all mixtures was significantly greater than that of the components in monoculture. The yield of a specific mixture was generally higher than the mean yield of its components but lower than that of the best component. Clay and Allard (1969) reported that in mixtures of 10 barley varieties the yields of three were significantly greater than those of the midcomponents, although no mixture yielded significantly better than its best component. The mean advantage of all 23 mixtures over their midcomponents was 1.5%. Early and Qualset (1971) found pure stands and mixtures of barley produced similar grain yields in two- and three-way mixtures. Complementary competition was observed in all mixtures involving the variety Tenn 60-30 as its yield was suppressed in mixtures by about 20% while the other component(s) increased by a similar amount. In rice, Roy (1960) found one mixture of two high yielding strains that exceeded the midcomponent by 12-27% and the better component by 11-20% for grain yield. Its relative advantage was greatest at low productivity levels (poorer soils).

Patterson et al. (1963) evaluated 15 1:1 mixtures of six spring oat varieties for grain yield and lodging resistance over four years. Generally, mixtures were superior in lodging resistance to the pure stand mean of the components, although none differed significantly from its midcomponent yield. Pfahler (1965) found the grain yield of a 1:1 mixture of two oat varieties was not signicantly different from that of the higher yielding variety. Jensen (1965) constructed 124 "general composites" of 5 to 16 oat lines and one "specific composite" of five oat lines. The general composites were formed without consciously selecting the lines to form the mixtures whereas the specific composite was composed of lines selected on the basis of anticipated favorable intrapopulation response. Averaged over eight years the mean yield of all general composites was 3.2% above that of their components, and over 10 locations in New York state the yield of the specific composite averaged 7.3% higher than the mean yield of its component lines. The specific composite was almost as productive as the component lines' mean at the highest yield level and superior at all other yield levels. The superiority became more marked with descending levels of yield. Jensen (1965) concluded that high yields should be possible with properly designed composites. Frey and Maldonado (1967) examined 57 mixtures among six oat cultivars in nonstress (normal planting) and stress (late planting) environments. The mean yield of all mixtures relative to the pure stand component yield was 100% in the nonstress environment and 104% in the stress environment. One and eight mixtures yielded significantly more than the mean of the components in nonstress and stress environments, respectively, and several mixtures yielded more than the best cultivar when averaged across both environments. They concluded that mixtures may be more suitable than monocultures under stress conditions. Browning (1957) similarly found that in an environment where stress existed as a result of an epidemic of stem rust, the yield of a mixture of resistant and susceptible oat lines exceeded the mean yield of the lines in monoculture.

The small number of mixtures that have been found superior to their best component for yield may be a result of the type of components used in the mixtures. Most mixtures have been compounded from varieties selected for high yield in monoculture; these components may not possess the precise biological properties necessary for large favorable interactions in mixed culture. Allard (1961) reported that $F_7$-$F_9$ bulks from biparental matings of three lima bean genotypes yielded significantly more than binary mixtures of the three parents. He concluded that natural selection during the bulk propagation phase may have favored high yielding compatible genotypes and that bulks may be a good source of genotypes to test in mechanical mixtures. Allard and Adams (1969) tested this hypothesis with two-way mixtures of eight $F_{18}$ derived lines from barley composite cross V. The relative yield (yield of a component in mixture relative to its pure stand yield) increase of components in mixture ranged from 0-12.7%. A parallel experiment with four commercial barley cultivars indicated that the relative yield increase of these components in mixtures was much smaller, ranging from -4.1% to 5.2%. Sammeta and Allard (unpublished results, cited in Allard and Adams, 1969) used a random sample of 29 genotypes from barley composite cross II and obtained results similar to those from composite cross V. Allard and Adams (1969) concluded that natural selection in mixed populations over time favored survival of genotypes which were good competitors, and at the same time, good neighbors, i.e., genotypes with superior "ecological combining ability".

The frequency of components influences the yield of mixtures in several crop species. The optimum frequencies for two-component soybean blends involved 70-90% of the component with the highest monoculture yield (Fehr and Rodriguez, 1974). Chapman et al. (1969) reported that in a mixture of two wheat cultivars the deviation of observed from expected yield (estimated from component monocultures) depended on the frequency of components in the mixture. The yield of 3:1, 1:1, and 1:3 mixtures of two oat cultivars did not differ significantly from that of the highest yielding component, although in corresponding mixtures of two rye cultivars (FB and G), the 1FB;3G mixture was significantly lower yielding than the higher yielding component FB (Pfahler, 1965). Grafius (1966) reported that in two two-component oat mixtures, Simcoe-Garry and Rodney-Garry, increasing the frequency of Simcoe or Rodney in 10% increments caused a nonlinear decrease in mixture yield. There was a mixture x frequency interaction because for Simcoe-Garry the observed yield was always less than the predicted one (weighted mean of the component monoculture yields) and for Rodney-Garry the observed yield was always greater than the predicted one. In contrast, Sakai (1957) found the change in yield of a test genotype was linearly proportional to the number of competing plants in rice and barley mixtures. Similarly, Khalifa and Qualset (1974) found no difference between observed and expected yields in a mixture of two wheat cultivars at seven component frequencies.

Many mixture experiments have involved only two- or three-component mixtures. Harper (1967) hypothesized that complex ecosystems are more efficient than simple ones in utilizing environmental resources. Thus, increasing the number of components in a mixture may enhance its yield relative to that of its components. However, results from several experiments (Frey and Maldonado, 1967, oats; Allard and Adams, 1969, barley and wheat; Clay and Allard, 1969, barley) indicate that increasing the number of components in a mixture does not increase its yield over that produced from monoculture planting of the components.

# MATERIALS AND METHODS

I conducted two experiments: experiment 1 compared the productivity of mixtures and monocultures of oat lines, and experiment 2 evaluated the lines used in experiment 1 in test mixtures (analogous to top crosses in cross-pollinated crops) as a method of identifying those lines that would combine to form high yielding mixtures.

## Formation of Mixtures

### Experiment 1 - mixtures and monocultures

I used 28 oat lines; eight were cultivars selected for high yield in monoculture and 20 were random lines from a population of 1,200 $F_9$-derived lines extracted from a bulk population. This bulk originated in 1958 by mixing $F_2$ seeds (10 g per cross) from 75 crosses. During bulk propagation from 1959 to 1965, the population was subjected to mass selection for resistance to crown rust, reduced plant height, and early maturity. In 1966, 10,000 $F_9$ spaced plants were grown and from these 1,200 random lines were derived, each the bulk progeny from one $F_9$ plant. I will refer to the 28 oat lines by the following line numbers:

| Line number | Material | Line number | Material |
|---|---|---|---|
| 1 | Grundy | 16 | Diana |
| 2 | Otee | 17 | Chief |
| 3 | Noble | 18 | Holden |
| 4 | Otter | 19 | Stout |
| 5-15 | Random lines | 20-28 | Random lines |

So lines 1-4 and 16-19 are the eight cultivars (chosen at random from all cultivars suitable for oat production in Iowa), and lines 5-15 and 20-28 are the random $F_9$-derived lines from the bulk population.

I constructed three diallel sets of two-component mixtures of oat lines. Each set consists only of the mixtures, not their reciprocals. Set one consisted of the 378 possible 1:1 mixtures among the 28 lines, set two consisted of the 105 possible 1:3 mixtures among the first 15 lines, and set three consisted of the 105 possible 3:1 mixtures of the same 15 lines. The 105 1:1 mixtures of the first 15 lines from set one will be designated 1:1a. Seed for each plot of a mixture was obtained by bulking the exact numbers of seeds of the components.

Experiment 2 - test mixtures

I mixed (by seed number) each of the 28 oat lines, in a frequency of 1:1, with each of six tester populations. The six testers represented two levels of diversity--homogeneous and heterogeneous--and three yield levels--high, medium, and low. McNeill (1969) tested the 1,200 random $F_9$-derived lines in six environments in three-replicate hill plot experiments in Iowa. I used mean grain yields from these experiments to subdivide the 1,200 lines into the three yield levels. The three lines with the highest, lowest, and mid grain yields, respectively, were used as the three homogeneous testers. The high yielding heterogeneous tester was formed by bulking equal numbers of seed from the four highest yielding lines, excluding the high-yield homogeneous tester line. The heterogeneous testers at the other yield levels were formed similarly. The heterogeneous testers were reconstituted from their four component lines for each plot involving that tester. None of the lines used as testers were included in the 20 random lines being evaluated in mixtures. Thus the 28 lines and six testers formed 168 test mixtures.

## Experimental Procedures

The two experiments were grown on Iowa State University experiment farms at Ames and Kanawha in 1974 and 1975. The planting dates in each environment are shown below, together with the environmental abbreviations that I shall use when convenient.

| Environment | Notation | Planting date |
|---|---|---|
| Ames 1974 | A74 | April 1, 1974 |
| Kanawha 1974 | K74 | April 3, 1974 |
| Ames 1975 | A75 | May 1, 1975 |
| Kanawha 1975 | K75 | May 5, 1975 |

The 1975 plantings were later than normal because of wet weather during April. The Ames site in central Iowa and the Kanawha site in northcentral Iowa have a rich glacial-till soil, 80 cm annual rainfall, and moderate temperatures for early spring growth. These sites are representative of the soil and climatic factors encountered in the oat-growing areas of central and northcentral Iowa.

A randomized complete block design with five replications was used in each environment for each experiment. Each replicate of experiment 1 contained 672 entries: 378 1:1 mixtures, 105 1:3 mixtures, 105 3:1 mixtures, and three pure stand plots of each of the 28 oat lines. Because each pure stand line mean was involved in comparisons with 27 or 14 mixture means, I included three pure stand plots of each line per replicate to obtain greater precision in the estimate of the line mean yield. Each replicate of experiment 2 contained 168 entries. Plots were hills spaced 30.5 cm apart in perpendicular directions and sown at a rate of 32 seeds per hill. Each experiment in each environment was surrounded by two rows of border hills to provide competitive balance for peripheral experimental hills. All plots were hoed to control weeds and sprayed with a fungicide (Maneb or Dithane M-45) at weekly intervals from anthesis to maturity to provide protection against crown rust (caused by <u>Puccinia</u> <u>coronata</u> Cda. var. avenae Frazier and Ledingham).

When mature, the plants of a plot were harvested at ground surface and the dry weight of the bundle of culms was measured. After threshing, grain yield was recorded for the plot and straw yield was calculated by subtracting grain weight from bundle weight. Both yields were converted to quintals per hectare.

## Statistical Procedures

### Experiment 1 - mixtures and monocultures

Combined analyses of variance across locations and years were carried out on lines and sets of mixtures using a randomized complete block design model (Snedecor and Cochran, 1967). Line, mixture, location, and year effects were considered random; replicate effects were considered fixed. I considered the lines to be random because they represented a random sample of released cultivars and unselected genotypes (for yield) obtained from bulks. Tests of significance of mean squares were made by the appropriate variance ratios where available. Approximate significance tests for main effects were obtained by Cochran's (1951) method. Variance components for lines, sets of mixtures, and interactions of these with locations and years were estimated from linear functions of appropriate mean squares. Standard errors of variance components were estimated by the method described by Comstock and Moll (1963).

Diallel analyses across locations and years (Rojas and Sprague, 1952; method 4, model 2, Griffing, 1956) were carried out on the sets of mixtures. The model used in these analyses can be represented by

$$
\begin{aligned}
Y_{ijkmq} = {} & \mu + l_k + t_m + (lt)_{km} + r_{kmq} + g_i + g_j + s_{ij} + \\
& (gl)_{ik} + (gl)_{jk} + (sl)_{ijk} + (gt)_{im} + (gt)_{jm} + \\
& (st)_{ijm} + (glt)_{ikm} + (glt)_{jkm} + (slt)_{ijkm} + e_{ijkmq}
\end{aligned}
$$

where $Y_{ijkmq}$ is the yield of the mixture between the ith and jth lines in the qth replicate of the trial conducted at the kth location in the mth year, $\mu$ is the overall mean, $l_k$ is the effect of the kth location, $t_m$ is the effect of the mth year, $r_{kmq}$ is the effect of the qth replicate within the kth location and mth year, $(g_i + g_j)$ is the general (GMA) effect of the ith and jth lines in a mixture, $s_{ij}$ is the specific (SMA) effect of the ith and jth lines in a mixture, and $e_{ijkmq}$ is the residual variation. The terms in parentheses represent interactions of main effects. The partition of variance and expected mean squares for the GMA and SMA effects and their interactions with locations and years are presented in Table 1. Significance tests were made with ratios of appropriate linear combinations of mean squares. Variance components and their standard errors were estimated as described above.

I compared mixtures and their component pure stands by calculating three types of relative mixture values (RMV), low, mid, and high, for each mixture. The relative mixture value is the ratio of the mixture yield to the lower, mid, or higher component pure stand yield, expressed as a percentage. Midcomponent values were the average component pure stand yields weighted by the frequency of the components in the mixture. Yields averaged over replicates, or over replicates, locations, and years, were used to calculate RMV's within and across environments, respectively.

I used t-tests to determine if RMV's were significantly

Table 1. Partition of variance and expected mean squares for general (GMA) and specific (SMA) mixing effects and their interactions with locations and years in the diallel analysis

| Source of variation | Degrees of freedom[a] | Expected mean squares |
|---|---|---|
| GMA | (n-1) | $\sigma^2 + r\sigma^2_{slt} + lr\sigma^2_{st} + tr\sigma^2_{sl} + ltr\sigma^2_{s} + (n-2)r\sigma^2_{glt} + (n-2)lr\sigma^2_{gt} + (n-2)tr\sigma^2_{gl} + (n-2)ltr\sigma^2_{g}$ |
| SMA | n(n-3)/2 | $\sigma^2 + r\sigma^2_{slt} + lr\sigma^2_{st} + tr\sigma^2_{sl} + ltr\sigma^2_{s}$ |
| GMA x Loc | (n-1)(l-1) | $\sigma^2 + r\sigma^2_{slt} + tr\sigma^2_{sl} + (n-2)r\sigma^2_{glt} + (n-2)tr\sigma^2_{gl}$ |
| SMA x Loc | n(n-3)(l-1)/2 | $\sigma^2 + r\sigma^2_{slt} + tr\sigma^2_{sl}$ |
| GMA x Yr | (n-1)(t-1) | $\sigma^2 + r\sigma^2_{slt} + lr\sigma^2_{st} + (n-2)r\sigma^2_{glt} + (n-2)lr\sigma^2_{gt}$ |
| SMA x Yr | n(n-3)(t-1)/2 | $\sigma^2 + r\sigma^2_{slt} + lr\sigma^2_{st}$ |
| GMA x Loc x Yr | (n-1)(l-1)(t-1) | $\sigma^2 + r\sigma^2_{slt} + (n-2)r\sigma^2_{glt}$ |
| SMA x Loc x Yr | n(n-3)(l-1)(t-1)/2 | $\sigma^2 + r\sigma^2_{slt}$ |
| Error | n(n-1)(r-1)(l-1)(t-1)/2 | $\sigma^2$ |

[a]Where n = number of lines, l = number of locations, t = number of years, and r = number of replications.

different from 100%. A close approximation to the error variance of the RMV ratio was derived by the method of statistical differentials (Kempthorne and Folks, 1971). Let the mid RMV for any mixture be

$$R_m = 100\ M/(p_1X_1 + p_2X_2)$$

where M is the mean mixture yield, $X_1$ and $X_2$ are the mean component pure stand yields, and $p_1$ and $p_2$ are the component frequencies. The expected value (E), over all mixtures, of $R_m$ is approximately

$$E(R_m) = 100\ E(M)/E(X)$$

where E(M) and E(X) are the mean yield of all mixtures and the mean yield of all components in pure stand, respectively. The error variance of $R_m$ is approximately

$$\mathrm{Var}(R_m) = 100^2[E(M)/E(X)]^2[C^2(M) + (p_1^2 + p_2^2)C^2(X)] \qquad (1)$$

where C( ) is the error coefficient of variation of the quantity in parentheses. The error variance for the high or low RMV can be obtained from equation 1 by setting $p_1 = 1$ and $p_2 = 0$.

I estimated two sets of repeatability parameters for the relative mixture values: (a) variance-component repeatability percentages across environments for low, mid, and high RMV's, and (b) realized repeatability percentages in each environment for high RMV's. I conducted a randomized complete block analysis of variance on the array of 378 low, mid, or high RMV's for 1:1 mixtures (105 RMV's for 1:3 or 3:1 mixtures) where environments were considered as blocks. The error variance from this analysis includes the mixture x environment interaction variance component for RMV. The variance-component repeatability percentage was computed on a mixture mean basis with the formula

$$h^2 = 100[V_g/(V_g + V_e/4)]$$

where $V_g$ and $V_e$ are the mixture and error variance components, respectively, from the analysis of variance described above.

Realized repeatability percentages (standardized) for the RMV relative to the high component were computed in each environment with the formula

$$h^2 = 100[(\bar{R}_{st} - \bar{R}_t)/S_t]/[(\bar{R}_{sa} - \bar{R}_a)/S_a]$$

where $\bar{R}_a$, $S_a$, and $\bar{R}_{sa}$ are the mean and phenotypic standard deviation of the 378 1:1 high RMV's (105 1:3 or 3:1 RMV's) and the mean high RMV of the selected mixtures, respectively, in the selection environment a, and $\bar{R}_t$, $S_t$, and $\bar{R}_{st}$ refer to the same statistics in the test environment t. Each environment was used as a selection environment, and for each case, the test environment was the average of the other three environments. A selection intensity of 10% was used to calculate realized heritability percentages.

I considered that for each of the 105 mixtures of the first 15 lines, there were five sets of component frequencies, 0:1, 1:3, 1:1, 3:1, and 1:0. The 0:1 and 1:0 sets were the pure stand means of the components. For each mixture I estimated the linear and quadratic variances associated with component frequency within environments and combined across environments. F values for these variances were calculated by using a pooled error variance from analyses of variance on pure stands and the three sets of mixtures 1:1a, 1:3 and 3:1.

<u>Experiment 2 - test mixtures</u>

A combined analysis of variance was carried out using a randomized complete block design model (Snedecor and Cochran, 1967). Line, year, and location effects were considered random, tester and replicate effects were considered fixed. F tests were made with ratios of appropriate linear combinations of mean squares (Cochran, 1951). Variance components and their standard errors were estimated for lines, testers, lines x testers, and the interactions of these with locations and years. I estimated the product moment correlation coefficient between the array of line means averaged over testers and the array of line means averaged over mixtures containing the lines from experiment 1.

# RESULTS

## Experiment 1 - Mixtures and Monocultures

### Coefficients of variability and mean yields

Coefficients of variability (CV's) in my experiment ranged from 13.9-22.5% for straw yield and from 12.6-17.7% for grain yield. CV's at Kanawha in 1975 (19-22% for straw, 16-18% for grain) were higher than in the other three environments (14-16% for straw, 13-16% for grain) because mean yields were lowest in this environment (Tables 2 and 3). Within environments, CV's for lines and the three mixture sets were similar, and generally, they were lower than the 15-25% range reported for hill plots in Iowa (Frey, 1965).

Mean straw yields were 12-16 q/ha higher, and mean grain yields 9-10 q/ha higher, in 1974 than in 1975 (Table 3), probably because planting was one month later in 1975 than in 1974. Note that the mean yield of all mixtures generally was similar to the mean yield of all lines used in the mixtures for both traits within and across environments, e.g., for straw, yield was 40.6 q/ha for lines (28) and 40.7 q/ha for 1:1 mixtures, and for grain, yield was 33.3 q/ha and 33.3 q/ha when averaged across locations and years. These results indicate, therefore, that no overall advantage or disadvantage existed for mixtures over their component lines tested in pure stand.

Table 2. Coefficients of variability for straw and grain yields for oat lines in pure stand and three mixture sets in four environments

| Source | Environment: Ames 1974 | Kanawha 1974 | Ames 1975 | Kanawha 1975 |
|---|---|---|---|---|
| | Straw yield | | | |
| Lines | 15.0 | 13.9 | 15.8 | 19.4 |
| 1:1 mixtures | 15.2 | 14.3 | 15.2 | 21.3 |
| 1:3 mixtures | 14.6 | 14.2 | 15.2 | 20.6 |
| 3:1 mixtures | 15.2 | 14.3 | 14.9 | 22.5 |
| | Grain yield | | | |
| Lines | 16.0 | 13.1 | 13.3 | 16.3 |
| 1:1 mixtures | 14.8 | 14.2 | 12.9 | 17.7 |
| 1:3 mixtures | 14.9 | 13.2 | 13.4 | 16.9 |
| 3:1 mixtures | 15.1 | 14.0 | 12.6 | 17.5 |

Combined analyses of variance

Mean squares from the combined analyses of variance of lines and mixtures are given in Table 4 for straw and grain yields. Associated variance components and their standard errors are presented in Table 5. Significant differences existed among lines and among mixtures within the 1:1, 1:1a, 1:3, and 3:1 mixture sets for both traits. However, none of the contrasts of lines vs. all mixtures, 1:1a vs. 1:3 and 3:1 mixtures, or 1:3 vs. 3:1 mixtures gave a significant mean square. Lines in pure stand interacted significantly with

Table 3. Mean straw and grain yields for oat lines and mixtures within and across environments

| Source[a] | Environment | | | | Average |
|---|---|---|---|---|---|
| | A74 | K74 | A75 | K75 | |
| | | | Straw yield[b] | | |
| Lines (28) | 56.9 | 38.7 | 40.2 | 26.5 | 40.6 |
| Lines (15) | 58.9 | 39.6 | 42.1 | 27.6 | 42.1 |
| 1:1 | 57.4 | 38.7 | 40.3 | 26.5 | 40.7 |
| 1:1a | 59.8 | 40.0 | 42.3 | 27.5 | 42.4 |
| 1:3 | 59.7 | 39.7 | 41.8 | 27.1 | 42.1 |
| 3:1 | 57.8 | 38.9 | 41.9 | 27.8 | 41.6 |
| SE 1 | 0.5 | 0.3 | 0.3 | 0.3 | 0.2 |
| SE 2 | 0.7 | 0.5 | 0.5 | 0.5 | 0.3 |
| | | | Grain yield[b] | | |
| Lines (28) | 40.7 | 35.5 | 30.2 | 26.8 | 33.3 |
| Lines (15) | 41.1 | 36.1 | 30.9 | 27.4 | 33.9 |
| 1:1 | 40.7 | 35.3 | 30.3 | 26.9 | 33.3 |
| 1:1a | 41.2 | 36.0 | 30.8 | 27.1 | 33.8 |
| 1:3 | 41.1 | 35.8 | 30.7 | 26.9 | 33.6 |
| 3:1 | 40.7 | 35.8 | 30.7 | 27.7 | 33.8 |
| SE 1 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 |
| SE 2 | 0.5 | 0.4 | 0.3 | 0.4 | 0.2 |

[a]Lines (28) = 28 lines; lines (15) = first 15 lines; SE 1 = standard error of difference between lines (28) and 1:1 mixtures; SE 2 = standard error of difference between lines (15) and 1:1a, 1:3, or 3:1 mixtures.

[b]Quintals/hectare.

Table 4. Mean squares from combined analyses of variance for straw and grain yields for oat lines in pure stand and mixtures evaluated across two locations and two years

| Source of variation[a] | Degrees of freedom | Mean squares: Straw yield | Mean squares: Grain yield |
|---|---|---|---|
| Lines | 27 | 599.0** | 232.5** |
| Lines vs. all mixtures | 1 | 1166.0 | 92.9 |
| Mixtures 1:1 | 377 | 135.2** | 66.9** |
| 1:1a | 104 | 106.8** | 68.0** |
| 1:1b | 272 | 117.2** | 64.1** |
| Mixtures 1:3 | 104 | 117.7** | 66.6** |
| Mixtures 3:1 | 104 | 96.9** | 74.2** |
| C1 | 1 | 387.9 | 109.7 |
| C2 | 1 | 320.1 | 83.1 |
| Lines x years | 27 | 172.1** | 72.3 |
| Lines vs. mixtures x years | 1 | 0.0 | 13.6 |
| 1:1 x years | 377 | 63.3** | 36.3** |
| 1:1a x years | 104 | 49.7 | 30.1 |
| 1:1b x years | 272 | 68.4** | 38.6** |
| 1:3 x years | 104 | 57.3 | 33.2 |
| 3:1 years | 104 | 56.2 | 34.3 |
| C1 x years | 1 | 0.9 | 1.9 |
| C2 x years | 1 | 65.4 | 0.0 |
| Lines x locations | 27 | 131.0* | 68.7 |
| Lines vs. mixtures x locations | 1 | 215.6 | 1.0 |
| 1:1 x locations | 377 | 50.4 | 28.7 |
| 1:1a x locations | 104 | 47.5 | 25.8 |
| 1:1b x locations | 272 | 49.4 | 29.9 |
| 1:3 x locations | 104 | 72.9 | 29.4 |
| 3:1 x locations | 104 | 61.0 | 28.5 |
| C1 x locations | 1 | 23.9 | 2.8 |
| C2 x locations | 1 | 10.0 | 14.4 |

[a]Lines = 28 oat lines in pure stand. 1:1 = 1:1 mixtures among 28 pure stand lines; 1:1a = 1:1 mixtures among first 15 pure stand lines; 1:1b = remaining 1:1 mixtures; 1:3 and 3:1 = 1:3 and 3:1 mixtures among first 15 pure stand lines. C1 = 1:1a vs. 1:3 and 3:1; C2 = 1:3 vs. 3:1.

*,**Significant at 5% and 1% levels, respectively.

Table 4. (Continued)

| Source of variation | Degrees of freedom | Mean squares: Straw yield | Mean squares: Grain yield |
|---|---|---|---|
| Lines x years x locations | 27 | 66.0* | 46.6** |
| Lines vs. mixtures x years x locations | 1 | 223.0 | 0.1 |
| 1:1 x years x locations | 377 | 47.1 | 26.8 |
| 1:1a x years x locations | 104 | 53.8 | 27.1 |
| 1:1b x years x locations | 272 | 44.7 | 26.7 |
| 1:3 x years x locations | 104 | 60.4* | 26.7 |
| 3:1 x years x locations | 104 | 56.0* | 27.8 |
| C1 x years x locations | 1 | 2.2 | 0.4 |
| C2 x years x locations | 1 | 44.0* | 6.7 |
| Lines x blocks/locations, years | 432 | 42.1 | 24.9 |
| Reps/lines, blocks, locations, years | 1120 | 40.7 | 24.1 |
| Lines vs. mixtures x blocks/locations, years | 16 | 38.1 | 29.2 |
| 1:1 x blocks/locations, years | 6032 | 44.0 | 24.8 |
| 1:1a x blocks/locations, years | 1664 | 46.2 | 24.5 |
| 1:1b x blocks/locations, years | 4352 | 43.1 | 24.9 |
| 1:3 x blocks/locations, years | 1664 | 44.8 | 24.3 |
| 3:1 x blocks/locations, years | 1664 | 46.4 | 25.3 |
| C1 x blocks/locations, years | 16 | 9.1 | 2.9 |
| C2 x blocks/locations, years | 16 | 9.2 | 3.6 |

years, locations, and years and locations for straw yield, but for grain yield only the second order interaction of lines with locations and years was significant. In contrast, mixture sets interacted significantly with years, locations, or years and locations only occasionally. The 1:1 mixtures x years interaction was significant for straw and grain yields,

Table 5. Variance components and standard errors[a] from combined analyses of variance for straw and grain yields of oat lines and mixtures evaluated across two locations and two years

| Component source | Trait | |
|---|---|---|
| | Straw yield | Grain yield |
| Lines | 181.0 ± 84.1 | 69.1 ± 33.8 |
| 1:1 | 34.3 ± 6.0 | 14.4 ± 3.1 |
| 1:1a | 31.7 ± 9.5 | 19.6 ± 5.7 |
| 1:1b | 22.1 ± 6.5 | 11.1 ± 3.6 |
| 1:3 | 23.9 ± 11.1 | 15.3 ± 5.8 |
| 3:1 | 17.8 ± 9.6 | 19.6 ± 6.2 |
| Lines x years | 106.1 ± 48.4 | 27.6 ± 22.6 |
| 1:1 x years | 16.1 ± 5.7 | 9.5 ± 3.3 |
| 1:1a x years | -4.1 ± 10.1 | 3.0 ± 5.6 |
| 1:1b x years | 23.6 ± 7.0 | 11.9 ± 4.0 |
| 1:3 x years | -3.0 ± 11.4 | 6.5 ± 5.9 |
| 3:1 x years | 0.3 ± 10.9 | 6.5 ± 6.1 |
| Lines x locations | 65.0 ± 38.5 | 22.1 ± 21.8 |
| 1:1 x locations | 3.3 ± 5.0 | 1.9 ± 2.9 |
| 1:1a x locations | -6.3 ± 9.9 | -1.3 ± 5.1 |
| 1:1b x locations | 4.6 ± 5.7 | 2.8 ± 3.4 |
| 1:3 x locations | 12.6 ± 13.0 | 2.7 ± 5.5 |
| 3:1 x locations | 5.0 ± 11.4 | 0.7 ± 5.5 |
| Lines x years x locations | 47.8 ± 35.1 | 43.5 ± 24.7 |
| 1:1 x years x locations | 6.2 ± 7.0 | 4.1 ± 4.0 |
| 1:1a x years x locations | 15.3 ± 15.1 | 5.3 ± 7.6 |
| 1:1b x years x locations | 3.4 ± 7.9 | 3.6 ± 4.7 |
| 1:3 x years x locations | 31.1 ± 16.9 | 4.8 ± 7.5 |
| 3:1 x years x locations | 19.1 ± 15.7 | 5.0 ± 7.8 |

[a]Variance components and standard errors x 10.

and the second order interaction for straw yield was significant for 1:3 and 3:1 mixtures. Note that the error mean squares were very similar for lines, 1:1, 1:1a, 1:3, and 3:1 mixtures for both traits.

Variance components from significant mean squares generally exceeded twice their standard errors (Table 5). Negative variance components probably resulted from sampling errors and really represent estimates of zero. For straw yield, the variance component for lines (181.0) was nearly twice as large as that for lines x years (106.1) which, in turn, was nearly two times larger than those for lines x locations (65.0) and lines x years x locations (47.8). Also, the variance components for lines (181.0 for straw and 69.1 for grain) were approximately five times larger than those for the 1:1 mixture sets (34.3 for straw and 14.4 for grain). Similarly, for both traits the variance components for lines x years, lines x locations, and lines x years x locations were much larger than their respective counterparts for 1:1 mixtures interacting with environments. The variance components for the five mixture sets were similar in magnitude.

These results indicate that fluctuations in straw or grain yields over locations and years were smaller for mixtures than for oat lines in pure stand. Perhaps this was due to the heterogeneity of the mixtures providing a degree of developmental homeostasis. If there was no competition between components in a mixture and the mixture yield was the mean of the yields of its components in pure stand, then the genetic variance associated with the 1:1 mixtures should be (P. N. Hinz, Statistics Department, I.S.U., personal communication):

$$(n-2)\sigma_g^2/2n \qquad (2)$$

where n is the number of lines in the diallel set (28 or 14) and $\sigma_g^2$ is the genetic variance among them. Note that as n becomes large, equation 2 approaches $\sigma_g^2/2$. If there was competition between components in a mixture, the genetic variance associated with 1:1 mixtures should be greater than that estimated by equation 2. Obviously the mathematical relationship between variances among oat lines and mixtures cannot explain why the observed genetic variance components for mixtures averaged only about one-fifth those for lines in pure stand.

Diallel analyses

Mean squares, variance components and their standard errors from combined diallel analyses across locations and years are given in Tables 6, 7, 8, and 9 for 1:1, 1:1a, 1:3, and 3:1 mixture sets, respectively. General mixing ability (GMA) was significant for straw and grain yields in the four mixture sets. However, specific mixing ability (SMA) was not significant for either trait in any of the mixture sets. GMA generally did not interact significantly with locations or years, but it tended to interact significantly with

Table 6. Mean squares, variance components, and standard errors from combined diallel analyses for straw and grain yields of 1:1 mixtures evaluated across two locations and two years

| Source[a] | Degrees of freedom | Mean squares: Straw yield | Mean squares: Grain yield | Variance components x 10: Straw yield | Variance components x 10: Grain yield |
|---|---|---|---|---|---|
| GMA | 27 | 1334.5** | 616.9** | 19.1 ± 7.0 | 8.3 ± 3.3 |
| SMA | 350 | 42.7 | 24.5 | -1.3 ± 3.3 | -1.1 ± 1.9 |
| GMA x years | 27 | 297.1** | 164.8** | 7.1 ± 3.2 | 3.6 ± 1.8 |
| SMA x years | 350 | 45.2 | 26.4 | 3.0 ± 4.7 | 2.7 ± 2.7 |
| GMA x locations | 27 | 155.5 | 90.4 | 1.7 ± 1.9 | 0.9 ± 1.1 |
| SMA x locations | 350 | 42.3 | 23.9 | 0.1 ± 4.5 | 0.2 ± 2.5 |
| GMA x years x locations | 27 | 110.7** | 67.7** | 5.3 ± 2.3 | 3.4 ± 1.4 |
| SMA x years x locations | 350 | 42.2 | 23.7 | -3.6 ± 6.6 | -2.2 ± 3.7 |

[a]GMA = general mixing ability; SMA = specific mixing ability.

**Significant at 1% level.

Table 7. Mean squares, variance components, and standard errors from combined diallel analyses for straw and grain yields of 1:1a mixtures evaluated across two locations and two years

| Source[a] | Degrees of freedom | Mean squares: Straw yield | Mean squares: Grain yield | Variance components x 10: Straw yield | Variance components x 10: Grain yield |
|---|---|---|---|---|---|
| GMA | 14 | 492.2** | 379.2** | 16.3 ± 7.0 | 11.2 ± 5.4 |
| SMA | 90 | 46.8 | 19.6 | 3.2 ± 6.7 | -0.1 ± 3.3 |
| GMA x years | 14 | 80.5 | 87.5 | -0.8 ± 3.4 | 3.8 ± 2.6 |
| SMA x years | 90 | 45.0 | 21.1 | -2.6 ± 9.7 | -3.7 ± 4.8 |
| GMA x locations | 14 | 76.5 | 41.1 | -1.0 ± 3.4 | 0.1 ± 1.6 |
| SMA x locations | 90 | 43.0 | 23.4 | -4.6 ± 9.5 | -1.5 ± 5.0 |
| GMA x years x locations | 14 | 94.0* | 41.6 | 7.1 ± 5.5 | 2.6 ± 2.3 |
| SMA x years x locations | 90 | 47.6 | 24.8 | 2.8 ± 14.4 | 0.7 ± 7.5 |

[a]GMA = general mixing ability; SMA = specific mixing ability.

*,**Significant at 5% and 1% levels, respectively.

Table 8. Mean squares, variance components, and standard errors from combined diallel analyses for straw and grain yields of 1:3 mixtures evaluated across two locations and two years

| Source[a] | Degrees of freedom | Mean squares | | Variance components x 10 | |
|---|---|---|---|---|---|
| | | Straw yield | Grain yield | Straw yield | Grain yield |
| GMA | 14 | 487.4* | 327.2** | 11.9 ± 7.4 | 9.8 ± 4.8 |
| SMA | 90 | 60.1 | 26.0 | 3.1 ± 8.0 | -1.9 ± 3.5 |
| GMA x years | 14 | 142.9 | 91.7 | 1.8 ± 5.2 | 0.9 ± 3.2 |
| SMA x years | 90 | 44.0 | 24.1 | -6.2 ± 9.8 | 4.9 ± 4.5 |
| GMA x locations | 14 | 155.5 | 58.6 | 1.5 ± 5.5 | -1.7 ± 2.6 |
| SMA x locations | 90 | 60.1 | 24.9 | 9.9 ± 11.5 | 5.7 ± 4.6 |
| GMA x years x locations | 14 | 125.6** | 74.9** | 11.6 ± 6.9 | 8.6 ± 4.1 |
| SMA x years x locations | 90 | 50.2 | 19.2 | 10.9 ± 15.1 | -10.2 ± 5.9 |

[a]GMA = general mixing ability; SMA = specific mixing ability.

*,**Significant at 5% and 1% levels, respectively.

Table 9. Mean squares, variance components, and standard errors from combined diallel analyses for straw and grain yields of 3:1 mixtures evaluated across two locations and two years

| Source[a] | Degrees of freedom | Mean squares | | Variance components x 10 | |
|---|---|---|---|---|---|
| | | Straw yield | Grain yield | Straw yield | Grain yield |
| GMA | 14 | 371.1* | 301.4* | 9.1 ± 5.9 | 8.6 ± 4.5 |
| SMA | 90 | 54.2 | 38.8 | 1.9 ± 7.2 | 4.5 ± 4.2 |
| GMA x years | 14 | 99.4 | 86.1 | -2.4 ± 4.4 | 0.4 ± 3.1 |
| SMA x years | 90 | 49.5 | 26.2 | 4.4 ± 9.9 | 5.8 ± 4.9 |
| GMA x locations | 14 | 157.2 | 57.4 | 2.4 ± 5.5 | -1.6 ± 2.6 |
| SMA x locations | 90 | 46.0 | 24.0 | 0.9 ± 9.5 | 3.5 ± 4.6 |
| GMA x years x locations | 14 | 125.7** | 75.0** | 12.3 ± 6.9 | 8.4 ± 4.1 |
| SMA x years x locations | 90 | 45.1 | 20.4 | -2.6 ± 13.7 | -9.7 ± 6.3 |

[a]GMA = general mixing ability; SMA = specific mixing ability.

*,**Significant at 5% and 1% levels, respectively.

locations and years. Interactions involving SMA were not significant in any mixture set for either trait. For straw and grain yields, the GMA variance components (19.1 and 8.3, respectively) were two to three times larger than those for GMA x years (7.1 and 3.6, respectively) and GMA x years x locations (5.3 and 3.4, respectively) in 1:1 mixtures (Table 6). However, in 1:3 and 3:1 mixtures the GMA variance components were of similar magnitude to the GMA x years x locations variance components for straw and grain yields (Tables 8 and 9).

Mean yields from pure stands and GMA effects for the 28 oat lines (averaged over years and locations) used in the 1:1 mixture set are given in Table 10, and comparable data for the 15 lines used in the 1:1a, 1:3, and 3:1 mixture sets are given in Table 11. Significant and highly positive correlations ($r = 0.81^{**}$ to $r = 0.91^{**}$) existed between the mean yields of lines in pure stand and their GMA effects in mixtures. For example, lines 6 and 9 for straw and lines 4, 6, and 9 for grain had highest pure-stand yields and the highest GMA effects in 1:1 mixtures. Also significant ($P \leq 0.01$) positive correlations existed between 1:1a and 1:3, 1:1a and 3:1, and 1:3 and 3:1 mixture sets for GMA effects of lines. These correlations were 0.86**, 0.70**, and 0.76**, respectively, for straw yield and 0.89**, 0.83**, and 0.76**, respectively, for grain yield.

Results from the diallel analyses indicate that there

Table 10. Mean yields of lines in pure stands and GMA effects in 1:1 mixtures averaged across years and locations

| Line no. | Straw yield: Pure stand mean | Straw yield: GMA effect | Grain yield: Pure stand mean | Grain yield: GMA effect |
|---|---|---|---|---|
| 1 | 37.6 | -1.05 | 33.3 | 0.15 |
| 2 | 43.1 | 1.13 | 32.7 | -0.33 |
| 3 | 38.9 | -0.25 | 33.8 | 0.11 |
| 4 | 44.4 | 2.29 | 36.8 | 2.00 |
| 5 | 39.7 | 0.24 | 32.6 | 0.07 |
| 6 | 45.2 | 3.14 | 38.4 | 2.98 |
| 7 | 39.1 | 0.13 | 33.8 | 0.62 |
| 8 | 44.8 | 1.63 | 32.2 | -1.05 |
| 9 | 48.1 | 3.52 | 37.4 | 1.98 |
| 10 | 39.0 | 0.64 | 32.1 | 0.29 |
| 11 | 39.3 | -1.55 | 32.0 | -1.39 |
| 12 | 40.0 | -1.23 | 35.8 | 0.63 |
| 13 | 44.4 | 1.26 | 31.6 | -1.30 |
| 14 | 43.9 | 1.37 | 32.3 | -0.10 |
| 15 | 43.6 | 0.86 | 33.0 | -0.51 |
| 16 | 39.0 | -2.12 | 31.8 | -1.32 |
| 17 | 39.4 | -0.73 | 35.1 | 0.37 |
| 18 | 37.8 | -0.57 | 32.9 | 0.32 |
| 19 | 33.8 | -3.49 | 30.2 | -1.53 |
| 20 | 39.1 | 0.27 | 32.9 | 0.73 |
| 21 | 37.4 | -2.01 | 32.9 | -0.58 |
| 22 | 39.6 | -0.90 | 34.5 | -0.04 |
| 23 | 43.6 | 1.05 | 30.4 | -1.57 |
| 24 | 38.0 | -0.69 | 33.4 | 0.34 |
| 25 | 37.5 | -1.85 | 34.1 | 0.42 |
| 26 | 41.6 | 0.04 | 32.2 | -0.52 |
| 27 | 39.7 | -0.60 | 33.5 | 0.19 |
| 28 | 38.7 | -0.53 | 30.8 | -0.98 |
| Standard error | 0.8 | 0.30 | 0.6 | 0.20 |
| Correlation[a] | | 0.91** | | 0.91** |

[a]Correlation between yields in pure stand and GMA effects.

**Significant at 1% level.

Table 11. Mean yields of lines in pure stands and GMA effects in 1:1a, 1:3, and 3:1 mixtures averaged across years and locations

| Line no. | Straw yield: Pure stand mean | Straw yield: GMA effect 1:1a | Straw yield: GMA effect 1:3 | Straw yield: GMA effect 3:1 | Grain yield: Pure stand mean | Grain yield: GMA effect 1:1a | Grain yield: GMA effect 1:3 | Grain yield: GMA effect 3:1 |
|---|---|---|---|---|---|---|---|---|
| 1 | 37.6 | -1.56 | -1.22 | -2.47 | 33.3 | -0.06 | 0.04 | 0.03 |
| 2 | 43.1 | 0.50 | -0.10 | 0.10 | 32.7 | -0.54 | 0.34 | -1.18 |
| 3 | 38.9 | -0.80 | -1.15 | -1.42 | 33.8 | -0.08 | -0.11 | 0.00 |
| 4 | 44.4 | 1.33 | 0.82 | 1.48 | 36.8 | 1.54 | 1.27 | 1.92 |
| 5 | 39.7 | -0.10 | -1.11 | -1.25 | 32.6 | 0.22 | -0.33 | -0.71 |
| 6 | 45.2 | 2.15 | 0.67 | 0.92 | 38.4 | 2.75 | 1.69 | 2.05 |
| 7 | 39.1 | -0.63 | 0.22 | -0.40 | 33.8 | 0.22 | 0.64 | 0.38 |
| 8 | 44.8 | 0.42 | 1.73 | 0.98 | 32.2 | -1.48 | -0.52 | -0.78 |
| 9 | 48.1 | 2.40 | 2.67 | 1.76 | 37.4 | 1.53 | 2.04 | 0.97 |
| 10 | 39.0 | -0.32 | -0.65 | 0.23 | 32.1 | -0.06 | -0.44 | 0.00 |
| 11 | 39.3 | -2.10 | -1.81 | -0.10 | 32.0 | -1.48 | -1.79 | -0.82 |
| 12 | 40.0 | -2.40 | -2.18 | -0.58 | 35.8 | 0.30 | 0.59 | 0.79 |
| 13 | 44.4 | 0.61 | 1.52 | 1.34 | 31.6 | -1.48 | -1.60 | -0.43 |
| 14 | 43.9 | 0.33 | 0.32 | -0.85 | 32.3 | -0.45 | -0.73 | -1.74 |
| 15 | 43.6 | 0.08 | 0.29 | 0.35 | 33.0 | -0.94 | -1.11 | -0.48 |
| Standard error | 0.9 | 0.40 | 0.40 | 0.40 | 0.7 | 0.30 | 0.30 | 0.30 |
| Correlation[a] | | 0.85** | 0.86** | 0.81** | | 0.91** | 0.89** | 0.89** |

[a]Correlation between yields in pure stand and GMA effects.

**Significant at 1% level.

was no "specific mixture vigor" in the mixtures of oat lines, i.e., the yield of an individual mixture did not deviate significantly from the mean yield of all mixtures containing either of its components. Furthermore, the yield of a line in pure stand was a good indicator of the yield of all mixtures involving that line (r = 0.91** for straw yield and r = 0.91** for grain yield). The similarity of GMA effects for lines in 1:1a, 1:3, and 3:1 mixture sets indicates that component frequency had little or no effect on deviations among yields of mixtures with a common component line. I shall consider the effects of component frequency in more detail later.

<u>Means, ranges, and frequency distributions of relative mixture values</u>

The mean, lowest, and highest relative mixture values (RMV's) for the oat mixtures are given in Table 12 for straw yield and Table 13 for grain yield. For the three mixture sets the mean RMV relative to the low component was always greater than 100%, the mean RMV relative to the midcomponent was within the range 90-101%, and the mean RMV relative to the high component was always less than 100%. The range of low, mid, or high RMV's was slightly greater within environments than when averaged across environments, and this resulted from both smaller and larger RMV's within environments. For example, across the three mixture sets the mid RMV's varied from 71-154% for straw yield and 71-137% for grain yield within environments, although they ranged from only 90-117% for straw

Table 12. Mean, lowest, and highest relative mixture values (RMV)[a] for straw yield in three mixture sets within and across environments

| Mixture set | Statistic | Ames 1974 | | | Kanawha 1974 | | | Ames 1975 | | | Kanawha 1975 | | | Combined | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Low | Mid | High | Low | Mid | High | Low | Mid | High | Low | Mid | High | Low | Mid | High |
| 1:1 | Mean | 107 | 101 | 96 | 105 | 100 | 96 | 107 | 100 | 95 | 106 | 100 | 95 | 105 | 100 | 96 |
| | Lowest | 84 | 80 | 75 | 75 | 75 | 71 | 83 | 76 | 70 | 76 | 74 | 69 | 91 | 91 | 83 |
| | Highest | 133 | 122 | 119 | 133 | 122 | 120 | 144 | 131 | 128 | 166 | 136 | 130 | 125 | 111 | 115 |
| 1:3 | Mean | 107 | 100 | 97 | 106 | 100 | 95 | 104 | 99 | 95 | 105 | 99 | 93 | 105 | 100 | 96 |
| | Lowest | 83 | 83 | 81 | 85 | 84 | 73 | 87 | 80 | 77 | 78 | 74 | 64 | 91 | 90 | 85 |
| | Highest | 131 | 119 | 119 | 131 | 124 | 119 | 129 | 120 | 120 | 134 | 127 | 125 | 120 | 110 | 110 |
| 3:1 | Mean | 104 | 100 | 94 | 104 | 99 | 94 | 104 | 100 | 95 | 108 | 101 | 96 | 103 | 100 | 95 |
| | Lowest | 83 | 80 | 72 | 83 | 71 | 67 | 87 | 86 | 81 | 82 | 78 | 73 | 92 | 91 | 82 |
| | Highest | 123 | 116 | 115 | 126 | 118 | 117 | 127 | 122 | 120 | 168 | 154 | 150 | 120 | 111 | 111 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

Table 13. Mean, lowest, and highest relative mixture values (RMV)[a] for grain yield in three mixture sets within and across environments

| Mixture set | Statistic | Ames 1974 | | | Kanawha 1974 | | | Ames 1975 | | | Kanawha 1975 | | | Combined | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Low | Mid | High | Low | Mid | High | Low | Mid | High | Low | Mid | High | Low | Mid | High |
| 1:1 | Mean | 103 | 100 | 97 | 105 | 100 | 95 | 106 | 100 | 95 | 105 | 101 | 96 | 103 | 100 | 97 |
| | Lowest | 79 | 77 | 75 | 78 | 76 | 75 | 86 | 85 | 78 | 73 | 71 | 69 | 92 | 89 | 85 |
| | Highest | 126 | 120 | 116 | 130 | 123 | 121 | 135 | 120 | 117 | 140 | 125 | 125 | 121 | 113 | 111 |
| 1:3 | Mean | 104 | 100 | 96 | 105 | 100 | 94 | 105 | 100 | 95 | 103 | 99 | 94 | 103 | 100 | 96 |
| | Lowest | 87 | 85 | 77 | 86 | 86 | 71 | 87 | 87 | 77 | 81 | 79 | 73 | 93 | 92 | 85 |
| | Highest | 137 | 118 | 114 | 130 | 121 | 112 | 141 | 115 | 110 | 129 | 126 | 123 | 115 | 106 | 104 |
| 3:1 | Mean | 103 | 99 | 96 | 105 | 98 | 94 | 105 | 100 | 95 | 106 | 101 | 97 | 103 | 99 | 96 |
| | Lowest | 82 | 81 | 73 | 84 | 78 | 74 | 86 | 85 | 81 | 80 | 79 | 77 | 91 | 89 | 84 |
| | Highest | 131 | 117 | 113 | 130 | 115 | 113 | 124 | 114 | 110 | 138 | 137 | 134 | 119 | 109 | 107 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

yield and 89-113% for grain yield when averaged over environments. The ranges for low, mid, and high RMV's for straw yield were similar to those for grain yield.

The frequency distributions of RMV's in 1:1 mixtures averaged across environments are given in Table 14 and those for 1:1 mixtures within environments are given in Table 15 for straw yield and Table 16 for grain yield. The corresponding results for 1:3 and 3:1 mixtures are given in Appendix Tables 31-36. The distributions for low RMV's were shifted upwards, i.e., greater than 100%; those for high RMV's were shifted downwards, i.e., less than 100%; and those for mid RMV's tended to be symmetrical around 100%. When averaged across environments, some mixtures exceeded their midcomponent means by up to 17% and their high yielding component by up to 15% for straw yield. The corresponding increases for grain yield were 13% and 11%, respectively. RMV's significantly different from 100% (two-tailed t test) occurred for low, mid, and high RMV types within and across environments. However, fewer than 5% of the mixtures had low RMV's significantly less than 100% at the 10% probability level (e.g., 6 and 4 out of 378 1:1 mixtures, for straw and grain, respectively, averaged over environments). Also, fewer than 5% of the mixtures had high RMV's significantly greater than 100% at the 10% probability level (e.g., 10 and 15 out of 378 1:1 mixtures for straw and grain, respectively, averaged over environments). However, more than 10% of the mixtures had mid RMV's significantly

Table 14. Frequency distribution of relative mixture values (RMV)[a] for straw yield and grain yield in 1:1 mixtures averaged across environments

| Class midpoint | Straw yield | | | Grain yield | | |
|---|---|---|---|---|---|---|
| | Low | Mid | High | Low | Mid | High |
| 84 | | | 2 | | | 1 |
| 87 | | | 20 | | | 5 |
| 90 | 1 | 5 | 46 | | 1 | 23 |
| 93 | 9 | 26 | 73 | 4 | 22 | 81 |
| 96 | 25 | 67 | 88 | 31 | 72 | 112 |
| 99 | 46 | 91 | 66 | 73 | 120 | 82 |
| 102 | 83 | 110 | 50 | 100 | 104 | 48 |
| 105 | 56 | 53 | 23 | 79 | 39 | 17 |
| 108 | 80 | 19 | 7 | 49 | 18 | 7 |
| 111 | 44 | 5 | 2 | 26 | 0 | 2 |
| 114 | 21 | 1 | 1 | 12 | 2 | |
| 117 | 9 | 1 | | 3 | | |
| 120 | 2 | | | 1 | | |
| 123 | 1 | | | | | |
| 126 | 1 | | | | | |
| Critical values[b] | | | | | | |
| P = .10 | 93<br>107 | 94<br>106 | 93<br>107 | 94<br>106 | 94<br>106 | 94<br>106 |
| P = .05 | 92<br>108 | 92<br>108 | 92<br>108 | 92<br>108 | 93<br>107 | 92<br>108 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

[b]For two-tailed t test.

Table 15. Frequency distribution of relative mixture values (RMV)[a] for straw yield in 1:1 mixtures within environments

| Class midpoint | Ames 1974 | | | Kanawha 1974 | | | Ames 1975 | | | Kanawha 1975 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low | Mid | High | Low | Mid | High | Low | Mid | High | Low | Mid | High |
| 68 | | | | | | | | | 1 | | | 2 |
| 73 | | | 1 | 1 | 1 | 3 | | | 1 | | 1 | 5 |
| 78 | | | 10 | 0 | 0 | 12 | | 1 | 7 | 2 | 6 | 23 |
| 83 | 2 | 7 | 29 | 3 | 7 | 21 | 3 | 6 | 28 | 7 | 13 | 39 |
| 88 | 10 | 20 | 50 | 9 | 22 | 54 | 8 | 23 | 71 | 11 | 43 | 70 |
| 93 | 22 | 60 | 85 | 44 | 76 | 90 | 28 | 68 | 96 | 41 | 72 | 70 |
| 98 | 49 | 87 | 94 | 60 | 95 | 93 | 71 | 109 | 84 | 73 | 81 | 70 |
| 103 | 89 | 113 | 66 | 98 | 101 | 63 | 70 | 72 | 46 | 73 | 67 | 42 |
| 108 | 82 | 57 | 28 | 67 | 49 | 28 | 76 | 56 | 29 | 68 | 36 | 25 |
| 113 | 68 | 24 | 11 | 47 | 20 | 10 | 56 | 32 | 13 | 29 | 31 | 13 |
| 118 | 39 | 8 | 4 | 28 | 6 | 3 | 37 | 10 | 1 | 26 | 9 | 12 |
| 123 | 11 | 2 | | 11 | 1 | 1 | 20 | 0 | 0 | 22 | 11 | 5 |
| 128 | 4 | | | 8 | | | 5 | 0 | 1 | 14 | 5 | 2 |
| 133 | 2 | | | 2 | | | 3 | 1 | | 8 | 2 | |
| 138 | | | | | | | 0 | | | 1 | 1 | |
| 143 | | | | | | | 1 | | | 2 | | |
| --- | | | | | | | | | | --- | | |
| 168 | | | | | | | | | | 1 | | |
| Critical values[b] | | | | | | | | | | | | |
| P = .10 | 87 | 88 | 87 | 88 | 89 | 88 | 87 | 88 | 87 | 82 | 83 | 82 |
| | 113 | 112 | 113 | 112 | 111 | 112 | 113 | 112 | 113 | 118 | 117 | 118 |
| P = .05 | 85 | 86 | 85 | 86 | 86 | 86 | 84 | 85 | 84 | 79 | 80 | 79 |
| | 115 | 114 | 115 | 114 | 114 | 114 | 116 | 115 | 116 | 121 | 120 | 121 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

[b]For two-tailed t-test.

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Table 16. Frequency distribution of relative mixture values (RMV)[a] for grain yield in 1:1 mixtures within environments

| Class midpoint | Ames 1974 | | | Kanawha 1974 | | | Ames 1975 | | | Kanawha 1975 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low | Mid | High | Low | Mid | High | Low | Mid | High | Low | Mid | High |
| 68 | | | | | | | | | | | | 1 |
| 73 | | | 1 | | | 1 | | | | 1 | 2 | 3 |
| 78 | 1 | 2 | 3 | 1 | 1 | 4 | | | 4 | 2 | 2 | 7 |
| 83 | 2 | 4 | 21 | 4 | 4 | 34 | | 2 | 23 | 4 | 10 | 31 |
| 88 | 18 | 27 | 43 | 12 | 30 | 65 | 3 | 19 | 67 | 16 | 35 | 50 |
| 93 | 35 | 61 | 95 | 32 | 67 | 91 | 25 | 71 | 106 | 38 | 57 | 99 |
| 98 | 71 | 95 | 89 | 58 | 101 | 98 | 77 | 114 | 92 | 56 | 87 | 71 |
| 103 | 101 | 111 | 84 | 94 | 101 | 45 | 87 | 95 | 63 | 83 | 77 | 50 |
| 108 | 91 | 52 | 28 | 87 | 46 | 32 | 84 | 55 | 18 | 70 | 59 | 37 |
| 113 | 38 | 19 | 13 | 56 | 22 | 5 | 46 | 15 | 3 | 49 | 30 | 22 |
| 118 | 15 | 6 | 1 | 20 | 4 | 2 | 38 | 7 | 2 | 34 | 13 | 4 |
| 123 | 5 | 1 | | 7 | 2 | 1 | 11 | | | 19 | 6 | 3 |
| 128 | 1 | | | 7 | | | 5 | | | 3 | | |
| 133 | | | | | | | 2 | | | 2 | | |
| 138 | | | | | | | | | | 1 | | |
| Critical values[b] | | | | | | | | | | | | |
| P = .10 | 87 | 88 | 87 | 88 | 89 | 88 | 89 | 90 | 89 | 85 | 88 | 85 |
| | 113 | 112 | 113 | 112 | 111 | 112 | 111 | 110 | 111 | 115 | 114 | 115 |
| P = .05 | 85 | 86 | 85 | 86 | 87 | 86 | 87 | 88 | 87 | 82 | 83 | 82 |
| | 115 | 114 | 115 | 114 | 113 | 114 | 113 | 112 | 113 | 118 | 117 | 118 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

[b]For two-tailed t-test.

different from 100% at the 10% probability level (e.g., 73 and 54 out of 378 1:1 mixtures for straw and grain, respectively, averaged over environments). Therefore, mixtures with low RMV's significantly less than 100% or with high RMV's significantly greater than 100% may have been in these outlying classes due to chance.

The distributions of mixtures significantly different from the low, mid, or high component monocultures are given in Table 17 for straw yield and Table 18 for grain yield. I obtained these distributions by testing whether the low, mid, and high RMV's were significantly different from 100%. For example, mixtures with mid and low RMV's significantly less than 100% were included in the "below $P_2$" class; mixtures with mid RMV's significantly less than 100% and low RMV which were less than 100%, but not significantly so, were included in the "equal $P_2$ or $P_2$ to $\bar{P}$" class. Note that most mixtures were not significantly different from the midcomponent for either trait in any of the three mixture sets. In 1:1 mixtures for both traits there was a trend for more mixtures to yield above the midcomponent than below the midcomponent. For example, when averaged over environments 42 mixtures were higher and 31 were lower than the midcomponent for straw yield; corresponding numbers for grain yield were 31 and 23 mixtures, respectively. This same trend existed for the 1:3 and 3:1 mixture sets. Also, a larger number of 1:1 mixtures had yields above the high monoculture component (10 for straw and 15 for grain) than

Table 17. Distribution of mixtures significantly[a] less or greater than component pure stands or equal to the mean of the component pure stands for straw yield, within and across environments for three mixture sets[b]

| Mixture set | Environment | Below $P_2$ | Equal $P_2$ or $P_2$ to $\overline{P}$ | Equal $\overline{P}$ | $\overline{P}$ to $P_1$ or equal $P_1$ | Above $P_1$ |
|---|---|---|---|---|---|---|
| 1:1 | A74 | 4 (2) | 13 (8) | 335 (356) | 18 (7) | 8 (5) |
| | K74 | 6 (5) | 17 (3) | 328 (355) | 15 (8) | 12 (7) |
| | A75 | 8 (2) | 10 (5) | 327 (356) | 23 (13) | 10 (2) |
| | K75 | 3 (2) | 9 (5) | 339 (351) | 15 (13) | 12 (7) |
| | Average | 5 (2) | 26 (6) | 305 (355) | 32 (7) | 10 (8) |
| 1:3 | A74 | 2 (1) | 1 (1) | 92 (98) | 5 (3) | 5 (2) |
| | K74 | 1 (1) | 2 (2) | 94 (95) | 5 (5) | 4 (2) |
| | A75 | 1 (0) | 6 (2) | 95 (100) | 1 (2) | 2 (1) |
| | K75 | 2 (1) | 3 (3) | 94 (98) | 4 (2) | 2 (1) |
| | Average | 2 (2) | 3 (3) | 97 (98) | 2 (1) | 1 (1) |
| 3:1 | A74 | 1 (1) | 3 (1) | 93 (101) | 5 (1) | 3 (1) |
| | K74 | 3 (3) | 12 (4) | 81 (89) | 5 (2) | 4 (3) |
| | A75 | 1 (0) | 6 (2) | 90 (98) | 6 (3) | 2 (2) |
| | K75 | 0 (0) | 7 (1) | 87 (98) | 5 (3) | 6 (3) |
| | Average | 3 (2) | 4 (3) | 89 (92) | 5 (6) | 4 (2) |

[a]Significant at 10% level; significant at 5% level in parentheses, both two-tailed tests.

[b]$P_2$ and $P_1$ are the yields of the lower and higher yielding pure stands, respectively. $\overline{P}$ is the midcomponent pure stand yield.

Table 18. Distribution of mixtures significantly[a] less or greater than component pure stands or equal to the mean of the component pure stands for grain yield, within and across environments for three mixture sets[b]

| Mixture set | Environment | Below $P_2$ | Equal $P_2$ or $P_2$ to $\bar{P}$ | Equal $\bar{P}$ | $\bar{P}$ to $P_1$ or equal $P_1$ | Above $P_1$ |
|---|---|---|---|---|---|---|
| 1:1 | A74 | 6 (3) | 17 (7) | 332 (355) | 12 (7) | 8 (3) |
| | K74 | 8 (5) | 18 (9) | 321 (348) | 20 (8) | 8 (5) |
| | A75 | 3 (1) | 18 (9) | 327 (353) | 22 (7) | 5 (5) |
| | K75 | 7 (4) | 12 (5) | 326 (352) | 21 (11) | 9 (3) |
| | Average | 4 (1) | 19 (12) | 321 (342) | 16 (16) | 15 (4) |
| 1:3 | A74 | 1 (0) | 4 (1) | 95 (102) | 4 (2) | 1 (0) |
| | K74 | 3 (1) | 3 (0) | 92 (101) | 6 (3) | 1 (0) |
| | A75 | 2 (0) | 4 (1) | 91 (101) | 8 (3) | 0 (0) |
| | K75 | 4 (3) | 6 (4) | 87 (94) | 5 (2) | 3 (2) |
| | Average | 1 (1) | 5 (0) | 96 (104) | 5 (0) | 0 (0) |
| 3:1 | A74 | 3 (2) | 8 (3) | 90 (99) | 3 (1) | 1 (0) |
| | K74 | 4 (3) | 6 (6) | 90 (93) | 4 (3) | 1 (0) |
| | A75 | 1 (1) | 7 (0) | 89 (100) | 8 (4) | 0 (0) |
| | K75 | 3 (1) | 5 (2) | 88 (95) | 2 (3) | 7 (4) |
| | Average | 5 (1) | 7 (7) | 87 (93) | 3 (4) | 3 (0) |

[a]Significant at 10% level; significant at 5% level in parentheses, both two-tailed tests.

[b]$P_2$ and $P_1$ are the yields of the lower and higher yielding pure stands, respectively. $\bar{P}$ is the midcomponent pure stand yield.

below the low monoculture component (5 for straw and 4 for grain.

I plotted RMV's of the 1:1 mixtures against the pure stand yield differences between the mixture components to examine whether large RMV's occurred in mixtures where the components had similar or dissimilar yields. Data averaged over locations and years were used for these graphs. RMV's relative to midcomponent values are plotted in Figures 1 and 2 for straw and grain, respectively, and those relative to the high component are plotted in Figures 3 and 4 for straw and grain, respectively. There was no linear association between mid RMV's and component yield differences for either straw (r = -0.06) or grain yield (r = 0.02). Significant negative correlations existed between RMV's relative to the high component and component yield differences for straw yield (r = -0.63**) and grain yield (r = -0.53**). RMV's relative to the high component that were above 102% generally occurred when the component yield differential was less than 2 q/ha for either straw or grain yield. Few mixtures exceeded their higher yielding component when the yield differential between components exceeded 7 q/ha for straw or 3 q/ha for grain.

Mean RMV's of mixtures with a common component, averaged over locations and years, are given in Tables 19, 20, and 21 for the 1:1, 1:3, and 3:1 mixture sets, respectively. RMV's relative to the low component for all lines were greater than 100% and most were significantly so. RMV's relative to the

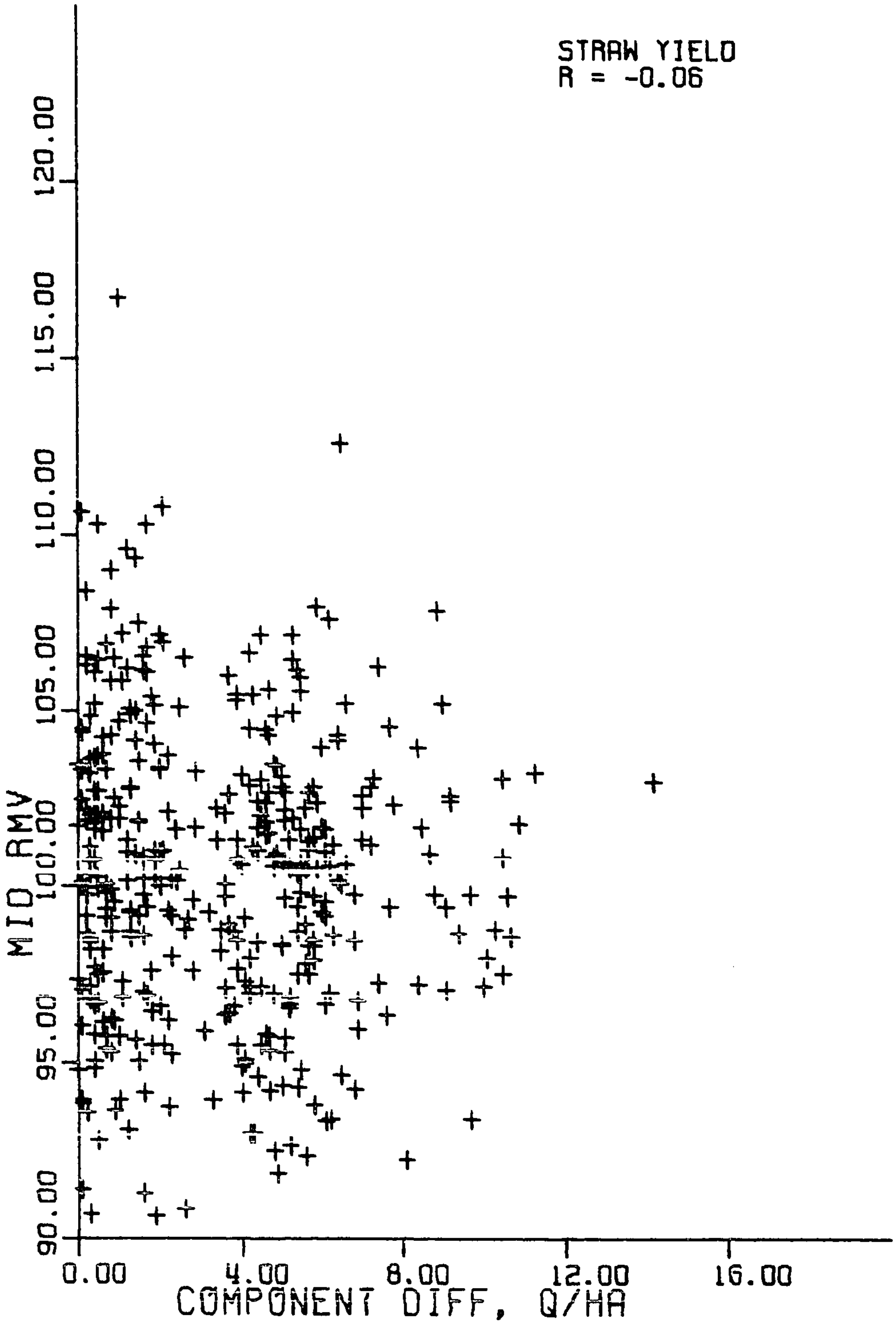



Figure 1. Scatter diagram for mid relative mixture values (RMV) for straw yield of 1:1 mixtures plotted against straw yield differentials between mixture components grown in pure stands

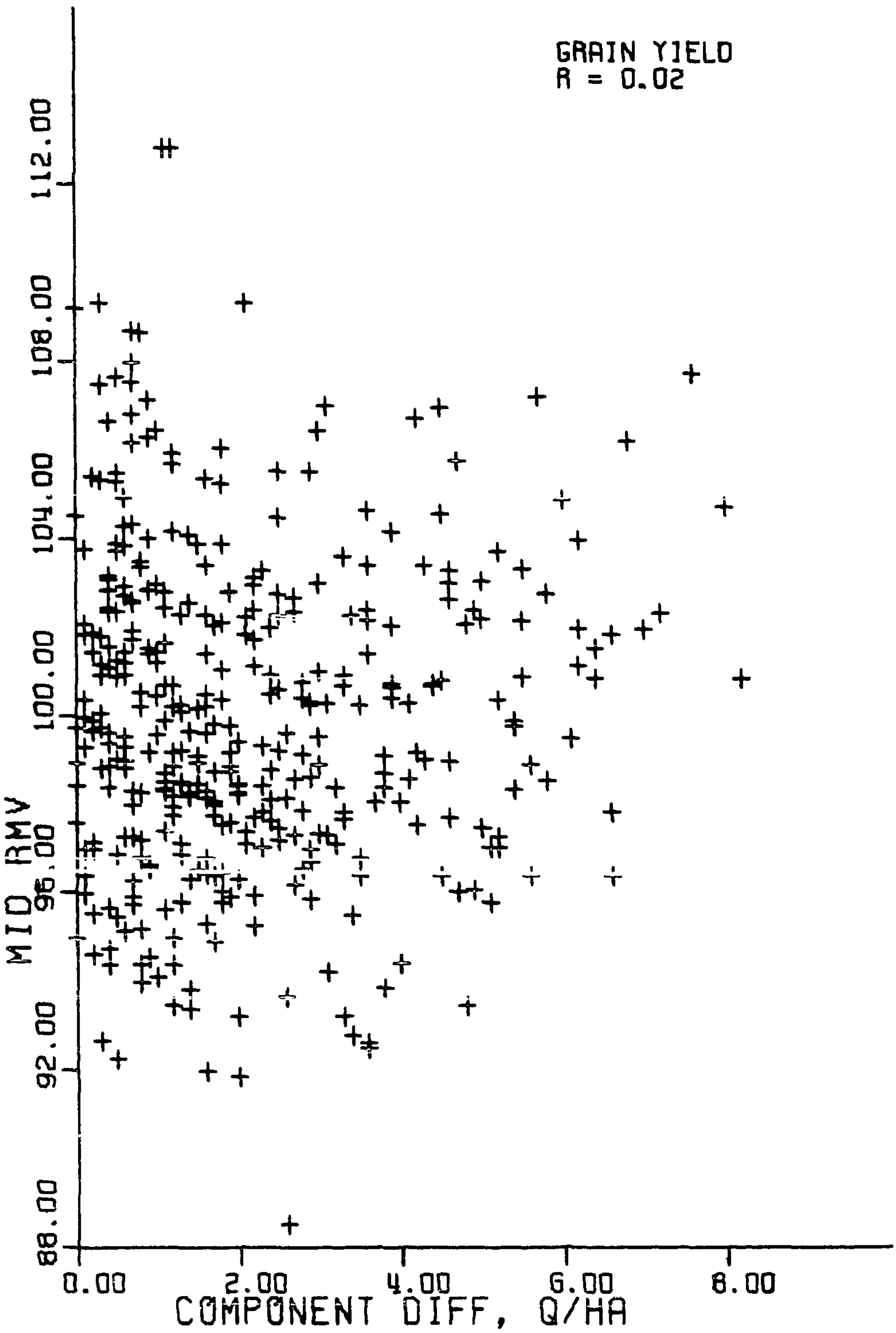



Figure 2. Scatter diagram for mid relative mixture values (RMV) for grain yield of 1:1 mixtures plotted against grain yield differentials between mixture components grown in pure stands

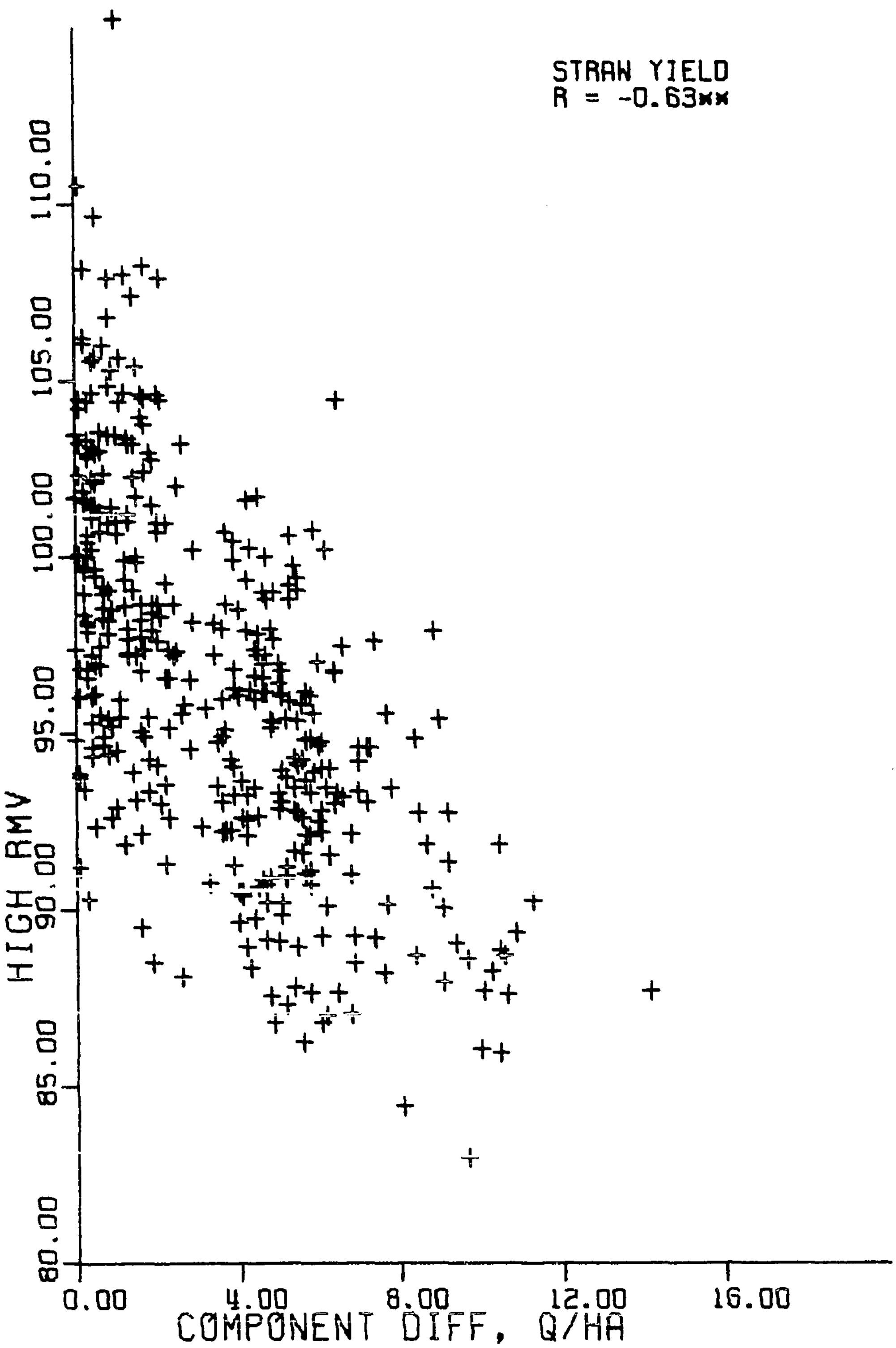



Figure 3. Scatter diagram for high relative mixture values (RMV) for straw yield of 1:1 mixtures plotted against straw yield differentials between mixture components grown in pure stands

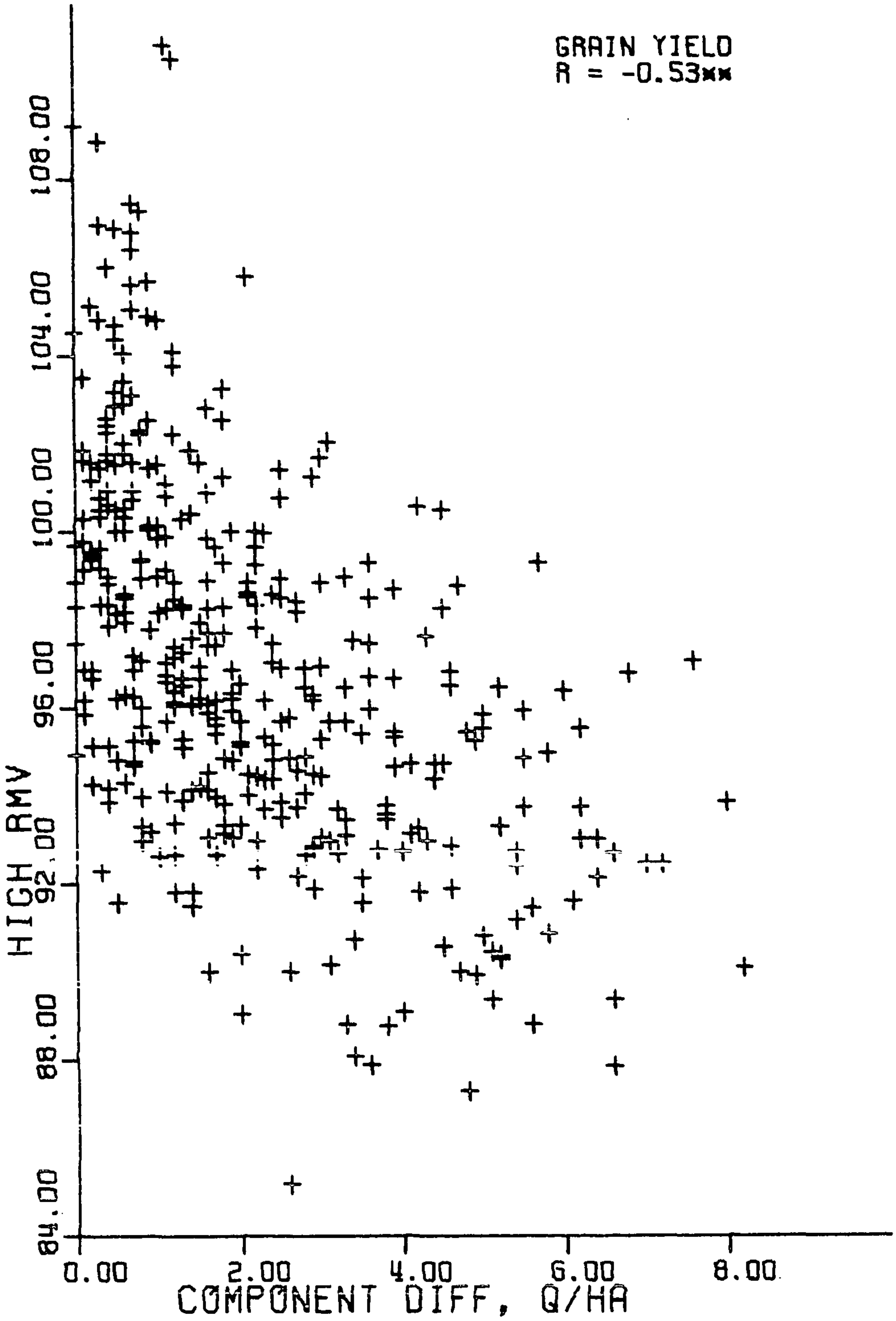



Figure 4. Scatter diagram for high relative mixture values (RMV) for grain yield of 1:1 mixtures plotted against grain yield differentials between mixture components grown in pure stands

Table 19. Mean relative mixture values (RMV)[a] of 1:1 mixtures with a common component line averaged across two locations and two years

| Component line | Straw yield Low | Straw yield Mid | Straw yield High | Grain yield Low | Grain yield Mid | Grain yield High |
|---|---|---|---|---|---|---|
| 1 | 106.1 | 101.5 | 97.5 | 102.9 | 100.5NS[b] | 98.4 |
| 2 | 104.6 | 100.0NS | 95.8 | 102.2 | 99.9NS | 97.8 |
| 3 | 105.3 | 101.8 | 98.8NS | 102.1 | 99.6NS | 97.2 |
| 4 | 106.9 | 101.3 | 96.4 | 106.6 | 100.7NS | 95.6 |
| 5 | 105.3 | 102.0 | 99.1NS | 103.7 | 101.3 | 99.1NS |
| 6 | 108.8 | 102.2 | 96.5 | 109.5 | 101.2 | 94.2 |
| 7 | 105.8 | 102.4 | 99.5NS | 103.7 | 101.1NS | 98.7 |
| 8 | 105.3 | 99.3NS | 94.1 | 101.0NS | 98.5 | 96.2 |
| 9 | 109.8 | 99.9NS | 91.8 | 106.5 | 99.8NS | 94.0 |
| 10 | 107.2 | 103.8 | 100.8NS | 105.2 | 102.6 | 100.1NS |
| 11 | 101.4 | 98.2 | 95.4 | 100.6NS | 97.9 | 95.5 |
| 12 | 101.4 | 98.2 | 95.3 | 102.8 | 98.3 | 94.2 |
| 13 | 104.4 | 98.9NS | 94.1 | 101.9 | 98.7 | 95.8 |
| 14 | 104.9 | 99.7NS | 95.2 | 103.6 | 101.2 | 98.9NS |
| 15 | 103.7 | 98.9NS | 94.6 | 101.2 | 99.0NS | 96.9 |
| 16 | 100.3NS | 97.1 | 94.3 | 101.3 | 98.4 | 95.8 |
| 17 | 103.2 | 100.0NS | 97.1 | 102.3 | 98.6 | 95.2 |
| 18 | 106.7 | 102.3 | 98.5 | 103.8 | 101.6 | 99.4NS |
| 19 | 110.4 | 100.1NS | 91.7 | 105.5 | 100.1NS | 95.4 |
| 20 | 106.0 | 102.7 | 99.8NS | 105.1 | 102.8 | 100.6NS |
| 21 | 104.1 | 99.3NS | 95.2 | 101.1NS | 98.9NS | 96.8 |
| 22 | 102.5 | 99.3NS | 96.4 | 101.3 | 98.1 | 95.2 |
| 23 | 104.2 | 99.4NS | 95.1 | 104.5 | 99.6NS | 95.3 |
| 24 | 106.0 | 101.8 | 98.2 | 103.2 | 100.9NS | 98.7 |
| 25 | 104.3 | 99.7NS | 95.6 | 102.9 | 100.1NS | 97.5 |
| 26 | 103.1 | 99.2NS | 95.7 | 102.7 | 100.2NS | 97.8 |
| 27 | 103.2 | 100.0NS | 97.2 | 102.7 | 100.3NS | 98.0 |
| 28 | 104.9 | 101.3 | 98.2 | 105.2 | 100.8NS | 96.9 |
| Standard error | 0.8 | 0.8 | 0.8 | 0.7 | 0.7 | 0.7 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

[b]NS = not significantly different from 100% at the 5% probability level.

Table 20. Mean relative mixture values (RMV)[a] of 1:3 mixtures with a common component line averaged across two locations and two years

| Component line | Straw yield | | | Grain yield | | |
|---|---|---|---|---|---|---|
| | Low | Mid | High | Low | Mid | High |
| 1 | 109.0 | 99.4NS[b] | 96.7 | 102.8 | 99.7NS | 97.7 |
| 2 | 102.2 | 98.9NS | 95.4 | 104.4 | 101.0NS | 99.3NS |
| 3 | 105.7 | 99.2NS | 96.9 | 101.7 | 98.8NS | 96.4 |
| 4 | 103.3 | 99.7NS | 95.8 | 104.0 | 100.0NS | 94.1 |
| 5 | 104.3 | 99.2NS | 96.5 | 102.8 | 99.8NS | 97.7 |
| 6 | 102.8 | 98.2 | 94.0 | 105.1 | 99.0NS | 91.6 |
| 7 | 108.4 | 103.2 | 99.9NS | 103.9 | 101.6 | 98.5NS |
| 8 | 105.3 | 100.4NS | 97.0 | 103.0 | 100.4NS | 97.5 |
| 9 | 107.4 | 98.9NS | 92.7 | 106.0 | 100.0NS | 94.7 |
| 10 | 106.7 | 102.8 | 98.3NS | 103.4 | 101.3NS | 97.7 |
| 11 | 103.4 | 99.7NS | 95.5 | 100.1NS | 97.9 | 94.1 |
| 12 | 101.4NS | 97.9 | 94.2 | 102.5 | 97.8 | 94.4 |
| 13 | 105.0 | 99.5NS | 97.3 | 101.7 | 99.5NS | 94.7 |
| 14 | 102.8 | 97.8 | 95.5 | 102.2 | 100.5NS | 97.0 |
| 15 | 102.9 | 98.2 | 95.8 | 99.9NS | 98.1 | 95.1 |
| Standard error | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

[b]NS = not significantly different from 100% at the 5% probability level.

Table 21. Mean relative mixture values (RMV)[a] of 3:1 mixtures with a common component line averaged across two locations and two years

| Component line | Straw yield | | | Grain yield | | |
|---|---|---|---|---|---|---|
| | Low | Mid | High | Low | Mid | High |
| 1 | 104.6 | 101.3NS[b] | 93.1 | 103.3 | 101.1NS | 98.3 |
| 2 | 101.4NS | 97.6 | 94.6 | 100.5NS | 98.8NS | 95.6 |
| 3 | 103.9 | 101.2NS | 95.4 | 102.5 | 99.9NS | 97.1 |
| 4 | 103.7 | 99.4NS | 96.1 | 106.4 | 99.8NS | 96.2 |
| 5 | 102.8 | 100.0NS | 95.5 | 102.2 | 99.9NS | 97.2 |
| 6 | 102.2 | 97.5 | 93.4 | 106.5 | 98.1 | 92.8 |
| 7 | 105.7 | 102.1 | 97.6 | 103.6 | 100.4NS | 98.3 |
| 8 | 102.6 | 98.7 | 94.4 | 102.7 | 99.4NS | 97.1 |
| 9 | 104.2 | 97.0 | 90.0 | 103.5 | 97.5 | 92.4 |
| 10 | 107.5 | 102.3 | 98.8NS | 105.1 | 101.1NS | 99.3NS |
| 11 | 106.2 | 101.4NS | 98.0 | 103.3 | 99.1NS | 97.1 |
| 12 | 103.9 | 99.7NS | 96.4 | 103.5 | 99.7NS | 95.4 |
| 13 | 103.3 | 100.8NS | 95.8 | 105.5 | 100.0NS | 98.1 |
| 14 | 98.8NS | 96.3 | 91.9 | 99.7NS | 95.9 | 94.5 |
| 15 | 101.7NS | 99.1NS | 94.8 | 102.1 | 98.9NS | 97.1 |
| Standard error | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

[b]NS = not significantly different from 100% at the 5% probability level.

midcomponent for many lines were not significantly different from 100% although they ranged from 97% to 104%. RMV's relative to the high component for most lines were significantly less than 100% and there was no line with a high RMV significantly greater than 100%. Several lines (e.g., lines 5, 10, and 20 in 1:1 mixtures), however, had high RMV's that were not significantly different from 100%. The same trends existed in all three mixture sets. For both straw and grain yields, lines 4, 6, and 9 had high mean yields in pure stand and high positive GMA effects in 1:1 mixtures (Table 10). However, mid RMV's for mixtures in which these lines occurred ranged from 99.8-102.2% and high RMV's all were significantly less than 100% (91.8-96.5%) (Table 19). Thus, although the yields of mixtures involving these lines were somewhat above average, all were inferior to the yields of their high components grown in pure stands.

These results suggest that even though high yielding mixtures existed, their yields were not superior to those of their higher yielding components. Of mixtures that differed from the midcomponent in yield, a slightly higher proportion showed a significant yield advantage than showed a significant yield disadvantage. In most cases, however, there was little or no advantage in grain or straw yield to be gained by mixing two oat cultivars or lines. Generally, therefore, the yield advantage of oat mixtures was insufficient to justify using mixtures for increased yield. I shall consider this in more detail later.

Relative mixture values for mixtures of cultivars and (or) lines of oats

I subdivided the 1:1 mixture set into three types on the basis of whether components were cultivars and (or) lines, i.e., cultivar-cultivar (c-c), cultivar-line (c-r), and line-line (r-r). These three types of mixtures were examined for range of RMV's to determine if the straw and grain yields of mixtures were associated with selection histories of the components in the mixtures. When averaged over locations and years the ranges of RMV's increased in the order c-c, c-r, r-r for both straw and grain yields (Tables 22 and 23). For example, ranges for RMV's relative to the midcomponent were 16, 20, and 26, respectively, for straw and 15, 17, and 24, respectively, for grain for the c-c, c-r, and r-r mixture types. For RMV's relative to the high component the corresponding ranges were 15, 25, and 31, respectively, for straw and 16, 22, and 26, respectively, for grain. This trend generally existed within locations also. The increases in ranges from c-c to c-r to r-r was due to expansion in both directions, i.e., a decrease in the lowest value (0-15% RMV) and an increase in the highest value (7-20% RMV).

Assuming that the yield increments of mixtures above their components in pure stand represent real effects, my results indicate that these increments were larger for mixtures of random lines than for mixtures of cultivars (Tables 22 and

Table 22. Lowest, highest, and range of relative mixture values (RMV)[a] for straw yield in cultivar-cultivar (c-c), cultivar-line (c-r), and line-line (r-r) mixtures in the 1:1 mixture set

| Mixture type | Statistic | Ames 1974 | | | Kanawha 1974 | | | Ames 1975 | | | Kanawha 1975 | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Low | Mid | High | Low | Mid | High | Low | Mid | High | Low | Mid | High | Low | Mid | High |
| c-c | Lowest | 94 | 92 | 90 | 90 | 89 | 79 | 87 | 87 | 83 | 85 | 81 | 78 | 92 | 91 | 89 |
| | Highest | 120 | 113 | 112 | 113 | 116 | 111 | 124 | 116 | 110 | 143 | 129 | 121 | 116 | 107 | 104 |
| | Range | 26 | 21 | 22 | 23 | 27 | 32 | 37 | 29 | 27 | 58 | 48 | 43 | 24 | 16 | 15 |
| c-r | Lowest | 84 | 80 | 75 | 83 | 82 | 74 | 83 | 76 | 70 | 76 | 74 | 71 | 93 | 91 | 83 |
| | Highest | 131 | 119 | 119 | 130 | 118 | 117 | 135 | 131 | 128 | 144 | 133 | 126 | 117 | 111 | 108 |
| | Range | 47 | 39 | 44 | 47 | 36 | 43 | 52 | 55 | 58 | 68 | 59 | 55 | 24 | 20 | 25 |
| r-r | Lowest | 88 | 85 | 77 | 75 | 75 | 71 | 86 | 83 | 77 | 79 | 77 | 69 | 91 | 91 | 84 |
| | Highest | 133 | 122 | 117 | 129 | 122 | 120 | 144 | 120 | 119 | 166 | 136 | 130 | 126 | 117 | 115 |
| | Range | 45 | 37 | 40 | 54 | 47 | 49 | 58 | 37 | 42 | 87 | 59 | 61 | 35 | 26 | 31 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

Table 23. Lowest, highest, and range of relative mixture values (RMV)[a] for grain yield in cultivar-cultivar (c-c), cultivar-line (c-r), and line-line (r-r) mixtures in the 1:1 mixture set

| Mixture type | Statistic | Ames 1974 | | | Kanawha 1974 | | | Ames 1975 | | | Kanawha 1975 | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Low | Mid | High | Low | Mid | High | Low | Mid | High | Low | Mid | High | Low | Mid | High |
| c-c | Lowest | 96 | 94 | 88 | 92 | 87 | 82 | 94 | 86 | 79 | 86 | 83 | 80 | 95 | 92 | 89 |
| | Highest | 123 | 119 | 115 | 127 | 112 | 110 | 119 | 116 | 114 | 131 | 124 | 116 | 113 | 107 | 105 |
| | Range | 27 | 25 | 27 | 35 | 25 | 28 | 25 | 30 | 35 | 45 | 41 | 36 | 18 | 15 | 16 |
| c-r | Lowest | 79 | 77 | 75 | 83 | 82 | 81 | 88 | 85 | 78 | 73 | 71 | 70 | 93 | 92 | 87 |
| | Highest | 125 | 116 | 113 | 125 | 118 | 111 | 130 | 112 | 110 | 134 | 125 | 124 | 117 | 109 | 109 |
| | Range | 46 | 39 | 38 | 42 | 36 | 30 | 42 | 27 | 32 | 61 | 54 | 54 | 24 | 17 | 22 |
| r-r | Lowest | 85 | 83 | 78 | 78 | 76 | 75 | 86 | 85 | 79 | 79 | 75 | 71 | 92 | 89 | 85 |
| | Highest | 126 | 120 | 116 | 130 | 123 | 121 | 135 | 120 | 117 | 140 | 125 | 125 | 121 | 113 | 111 |
| | Range | 41 | 37 | 38 | 52 | 47 | 46 | 49 | 35 | 38 | 61 | 50 | 54 | 29 | 24 | 26 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

23). For example, averaged over locations and years there were up to 17% and 13% increments above the midcomponent for straw and grain yield, respectively, in r-r mixtures compared with 7% and 7% increments for these traits in c-c mixtures. This suggests that there is a relationship between selection history of oat strains and positive mixing ability. Random lines used in my study had survived nine generations of natural selection in competition with a diverse array of genotypes, whereas the cultivars were developed in pedigree breeding programs designed to identify types with superior performance in pure stand. Natural selection in the bulk population seems to favor survival of genotypes with superior mixing ability.

Repeatability of relative mixture values

The yield advantage of mixtures over their components has to be repeatable across environments if mixtures are to be used commercially for increased yield. I estimated two repeatability parameters for relative mixture values. The variance component repeatability percentages (Table 24) estimate the consistency of the arrays of the 378 RMV's for 1:1 mixtures (105 RMV's for 1:3 or 3:1 mixtures) across the four environments A74, K74, A75, and K75. These repeatability percentages varied from 0-37%, and generally they were quite low for the three RMV types in each mixture set for straw and grain yields. The low RMV's had the highest repeatability (28-37% for straw,

Table 24. Variance component repeability percentages[a], across environments, of relative mixture values (RMV)[b] for straw and grain yields in three mixture sets

| Mixture set | RMV type | Trait | |
|---|---|---|---|
| | | Straw yield | Grain yield |
| 1:1 | Low | 32 | 24 |
| | Mid | 10 | 2 |
| | High | 15 | 5 |
| 1:3 | Low | 37 | 12 |
| | Mid | 0 | 0 |
| | High | 0 | 18 |
| 3:1 | Low | 28 | 34 |
| | Mid | 7 | 9 |
| | High | 16 | 26 |

[a]See Materials and Methods section for description and formula.

[b]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

12-34% for grain) although practically this result is not very useful. Variance component repeatability percentages varied from 0-10% for straw and 0-9% for grain for the mid RMV's. Corresponding ranges for the high RMV's were 0-16% for straw and 5-26% for grain.

Realized repeatability percentages (Table 25) involved only mixtures in the upper 10% of the array of RMV's relative to the high component in a particular environment. Low

Table 25. Realized repeatability percentages (10% selection intensity) for high RMV[a] for straw and grain yields in three mixture sets within and across environments

| Mixture set | Environment | Trait | |
|---|---|---|---|
| | | Straw yield | Grain yield |
| 1:1 | A74 | 14 | 9 |
| | K74 | 23 | 20 |
| | A75 | 12 | 14 |
| | K75 | 5 | 0 |
| | Mean | 13 | 11 |
| 1:3 | A74 | 2 | 0 |
| | K74 | 13 | 30 |
| | A75 | 8 | 0 |
| | K75 | 9 | 0 |
| | Mean | 8 | 8 |
| 3:1 | A74 | 33 | 24 |
| | K74 | 20 | 26 |
| | A75 | 12 | 11 |
| | K75 | 13 | 4 |
| | Mean | 20 | 16 |

[a]High RMV = mixture yield relative to high component pure stand yield.

repeatability percentages, that I obtained with this method, indicate that mixtures with elite high RMV's in one environment did not tend to maintain their elite high RMV's when averaged over the remaining environments. I calculated realized repeatability percentages only for high RMV because the yield advantage required to justify the use of mixtures should be superiority of yield of the mixture over that of its highest yielding component in monoculture. The realized repeatability percentages varied from 2-33% for straw yield and from 0-30% for grain yield, and generally, they would be classed as quite low in most environments for each mixture set.

My results indicate that yield differentials between mixtures and their components grown in monoculture generally were not repeatable across environments. This was not due to large errors associated with the RMV ratio. CV's averaged over low, mid, and high RMV's (Table 26) varied from 16.0-23.9% for straw yield and from 14.6-19.8% for grain yield within environments. These CV's were only slightly larger than those (Table 2) for actual straw (13.9-22.5%) and grain yields (12.6-17.7%).

Yields of mixtures and pure stands

To examine the relationship between the productivity of mixtures and their midcomponent means over the range of yields represented by mixtures and lines, I calculated the regression of mixture mean yields on corresponding midcomponent mean yields (averaged over locations and years) for 1:1 mixtures. Assuming that a mixture mean equals the midcomponent mean throughout the whole range of yields, the expected slope of the regression line can be calculated from the following equation (Snedecor and Cochran, 1967):

Table 26. Coefficients of variability averaged across low, mid, and high relative mixture values (RMV)[a] for straw and grain yields in three mixture sets within and across environments

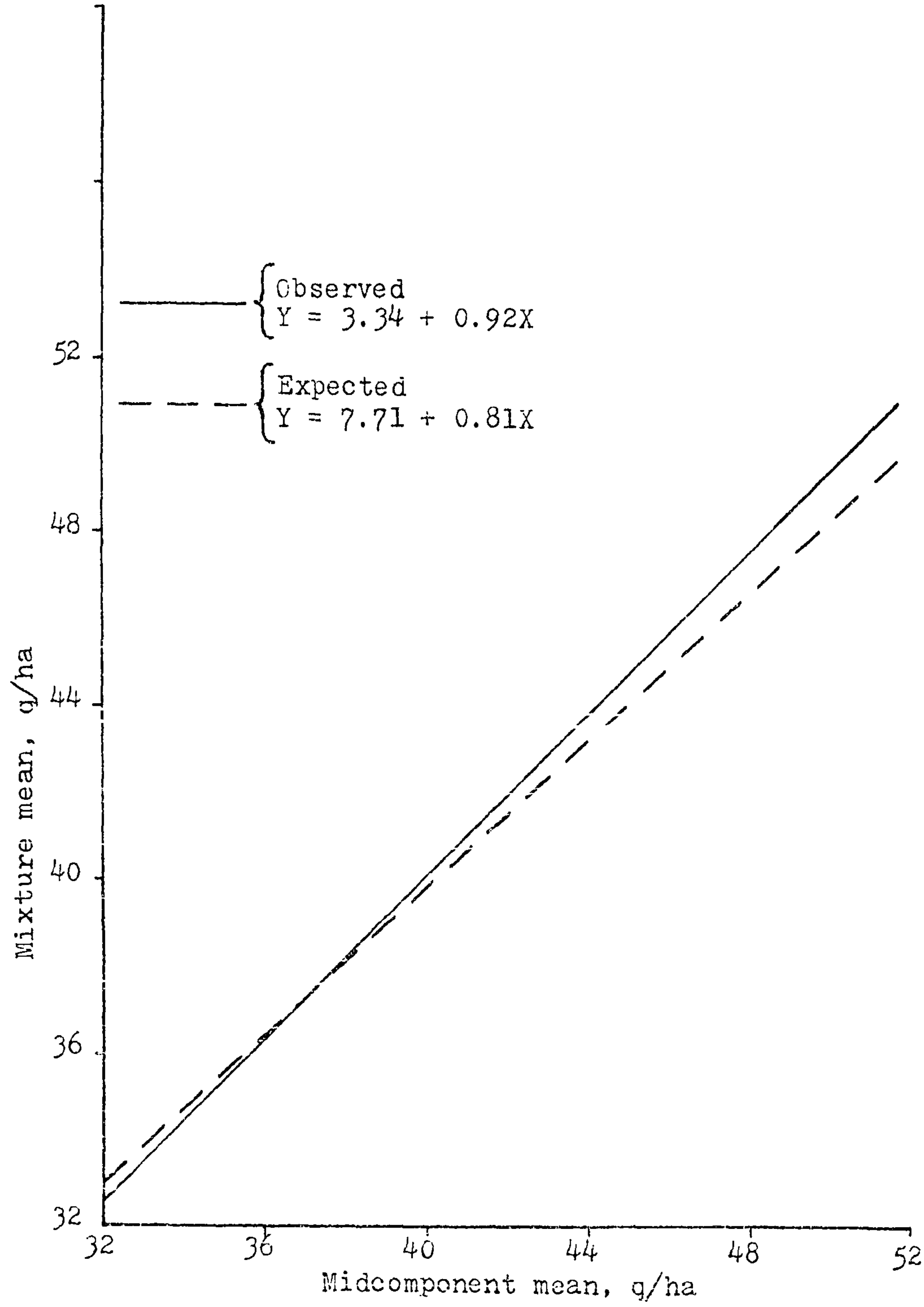
| Mixture set | Environment | | | | |
|---|---|---|---|---|---|
| | A74 | K74 | A75 | K75 | Combined |
| | | | Straw yield | | |
| 1:1 | 17.1 | 16.0 | 17.3 | 23.4 | 18.3 |
| 1:3 | 17.0 | 16.3 | 17.5 | 23.5 | 18.4 |
| 3:1 | 17.1 | 16.1 | 17.2 | 23.9 | 18.4 |
| | | | Grain yield | | |
| 1:1 | 17.0 | 15.8 | 14.7 | 19.7 | 16.7 |
| 1:3 | 17.1 | 15.5 | 14.9 | 19.5 | 16.8 |
| 3:1 | 17.3 | 15.9 | 14.6 | 19.8 | 16.9 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

$$E[b] = \sigma_g^2/(\sigma_g^2 + \sigma^2) = 1/(1 + \sigma^2/\sigma_g^2) \quad ,$$

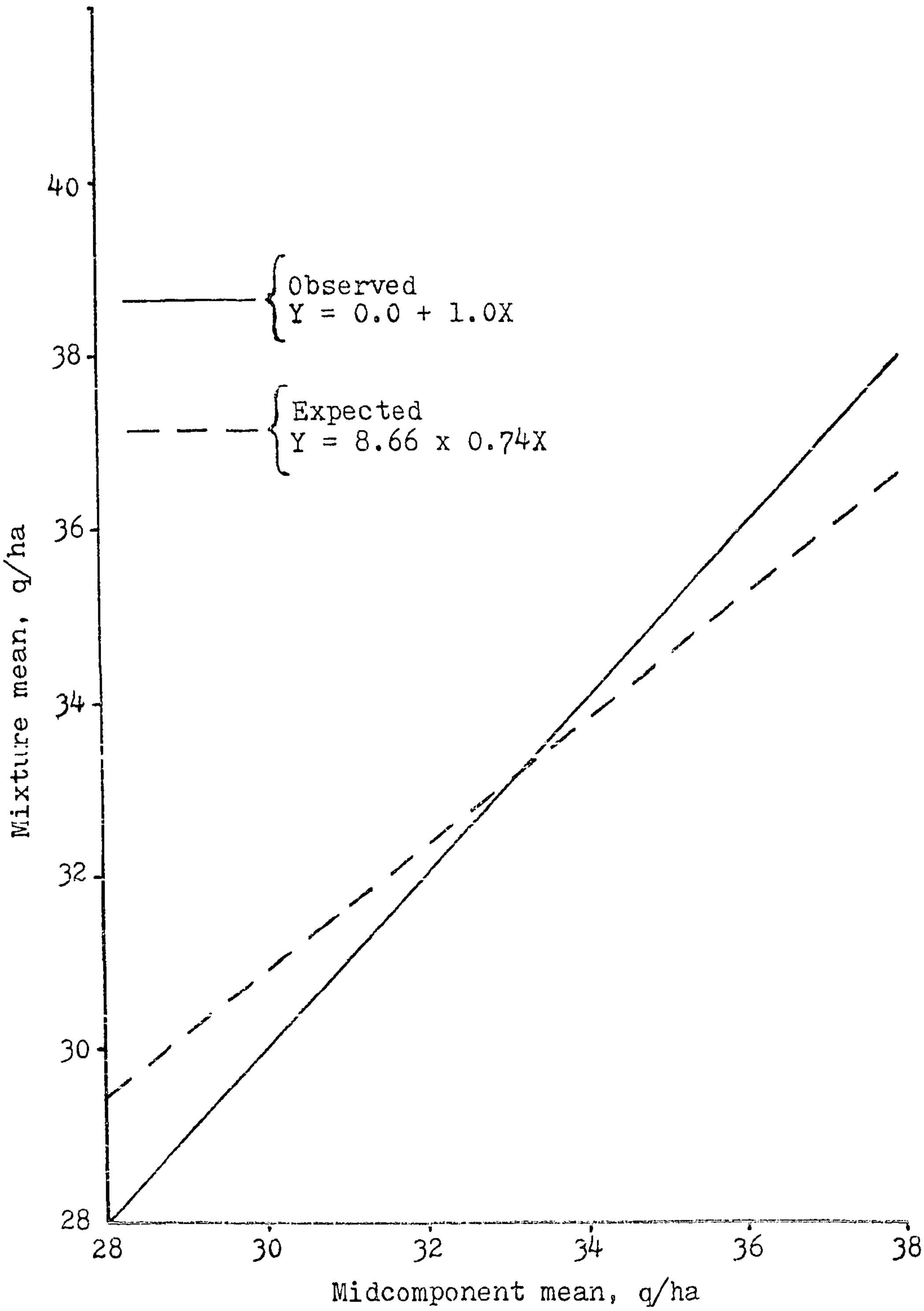
where $\sigma_g^2$ is the genetic variance component among lines and $\sigma^2$ is the error variance associated with lines or mixtures. Note that E[b] will always be less than unity because line mean yields always would be measured with error. The observed and expected regression lines are plotted in Figure 5 for straw yield and Figure 6 for grain yield. The observed regression was significant ($P \leq 0.01$) for both traits with a coefficient

Figure 5. Observed and expected regressions of mixture mean on midcomponent mean for straw yield



Observed
Y = 3.34 + 0.92X
Expected
Y = 7.71 + 0.81X
Mixture mean, q/ha
Midcomponent mean, q/ha
32
36
40
44
48
52

Figure 6. Observed and expected regressions of mixture mean on midcomponent mean for grain yield


Observed
Y = 0.0 + 1.0X
Expected
Y = 8.66 x 0.74X
Mixture mean, q/ha
Midcomponent mean, q/ha
28
30
32
34
36
38
40

of determination ($R^2$) of 0.58 for straw yield and 0.56 for grain yield. For both traits the observed slope (0.92 ± 0.04 for straw and 1.00 ± 0.05 for grain) was greater than the expected one (0.81 for straw, 0.74 for grain), with the differential being larger for grain than for straw yield. Note that the observed and expected regression lines intersect within the range of midcomponent mean yields encountered in my experiment. The plots in Figures 5 and 6 indicate that mixture mean yields did not equal the midcomponent mean yields over all yield levels. At low values for the midcomponent (less than 38 q/ha for straw and 33.5 q/ha for grain), mixtures, on average, yielded less than their midcomponents, whereas at high levels of midcomponent yields (greater than 38 q/ha for straw and 33.5 q/ha for grain), mixtures tended to yield more than their midcomponents.

To determine the magnitude of the yield advantage at these upper yield levels, I examined the 30 entries (from the 378 1:1 mixtures and 28 lines) with the highest straw or grain yields averaged over locations and years. For straw yield, these 30 entries consisted of 25 mixtures and five lines, and of the 25 mixtures, 23 had at least one of the five top yielding lines as a component. For grain yield the 30 entries consisted of 27 mixtures and three lines, and of the 27 mixtures, 23 had at least one of the three top yielding lines as a component. Mean yields of the lines and the five highest yielding mixtures included in the groups of 30 entries are given in Table 27. The straw yield of the best mixture (48.5 q/ha for 2, 8) exceeded that of its highest yielding component (44.8 q/ha for line 8) by 8.3%. However, this mixture was only 0.4 q/ha, or 0.8%, higher yielding than the best line (line 9 with 48.1 q/ha). This difference was not statistically significant (LSD = 4.1 q/ha). For grain yield the highest yielding mixture (38.4 q/ha for 6, 9) was formed from the two highest yielding lines (line 6 with 38.4 q/ha and line 9 with 37.4 q/ha). Furthermore, the yield of this mixture was exactly equal to the yield of the best line (line 6). Although the yield advantage of mixtures over their midcomponent means increased as the yield level increased, the highest yielding mixtures were no better than either their highest yielding component or the highest yielding line in test. Therefore the use of mixtures of oat cultivars or lines to obtain a yield advantage would not be justified when one compares the best mixtures with the best pure lines.

Linear and quadratic effects of component frequency

For each of the 105 mixtures involving the first 15 oat lines there were five sets of component frequencies, 0:1, 1:3, 1:1, 3:1, and 1:0. In each mixture, I estimated the straw or grain yield response to changing frequency of components by calculating the linear and quadratic variances associated with component frequency. I calculated F values for these variances

Table 27. Oat lines and mixtures with the highest straw and grain yields averaged over locations and years

| Line | Yield | Mixture | Yield | Advantage of mixture over high component (%) |
|---|---|---|---|---|
| | | Straw yield[a] | | |
| 9 | 48.1 | 2,8 | 48.5 | 8.3 |
| 6 | 45.2 | 6,9 | 48.2 | 0.2 |
| 8 | 44.8 | 4,9 | 47.5 | -1.2 |
| 4 | 44.4 | 6,13 | 47.4 | 4.9 |
| 13 | 44.4 | 6,15 | 47.3 | 4.6 |

LSD (5% level) for lines or mixtures = 4.1.

| Line | Yield | Mixture | Yield | Advantage of mixture over high component (%) |
|---|---|---|---|---|
| | | Grain yield[a] | | |
| 6 | 38.4 | 6,9 | 38.4 | 0.0 |
| 9 | 37.4 | 2,6 | 38.1 | -0.8 |
| 4 | 36.8 | 9,20 | 37.6 | 0.5 |
| | | 6,25 | 37.5 | -2.3 |
| | | 6,28 | 37.3 | -2.9 |

LSD (5% level) for lines or mixtures = 3.1

[a]Quintals/hectare.

in each mixture by using a pooled error variance obtained from analyses of variance on lines and the three sets of mixtures, 1:1a, 1:3, and 3:1. The frequency distributions of these F values for the 105 mixtures are given in Table 28 for straw yield and Table 29 for grain yield. If the pure stand yields of the two components of a mixture (i.e., the 0:1 and 1:0 frequency sets) were similar, it is unlikely a linear or quadratic trend would exist as component frequency changed. This may explain partially the high frequency of mixtures with low F values. Also the F test used approximates the $\chi^2$ distribution with 1 df. The density function for a $\chi^2$ approaches a hyperbola in the first quadrant. Thus, under the null hypothesis of no linear or quadratic effects, one would expect a high frequency of F values close to zero.

Within environments 11 to 23 mixtures for straw yield and 7 to 30 mixtures for grain yield had significant F values ($P \leq 0.05$) for the linear effect. In contrast only zero to two mixtures for straw yield and zero to three mixtures for grain yield had significant F values ($P \leq 0.05$) for the quadratic effect within environments. Five and seven mixtures had significant linear effects ($P \leq 0.05$) for straw and grain yield, respectively, and none of the mixtures had significant quadratic effects for either trait when data were averaged over locations and years. The presence of significant linear response but no quadratic response to changing component frequency in some mixtures indicates that the components of

Table 28. Frequency distributions for F values for linear and quadratic responses of straw yield to variation in frequency of mixture components in 105 mixtures within and across environments

| Environment | Polynomial | Class interval 0.00–0.29 | 0.30–0.59 | 0.60–0.89 | 0.90–1.19 | 1.20–1.99 | 2.00–3.99 | 4.00–6.99 | > 7.00 | No. sig.[a] |
|---|---|---|---|---|---|---|---|---|---|---|
| A74 | Linear | 23 | 13 | 12 | 12 | 12 | 13 | 15 | 5 | 20 |
| | Quadratic | 58 | 15 | 9 | 7 | 10 | 4 | 2 | 0 | 2 |
| K74 | Linear | 37 | 12 | 12 | 7 | 3 | 12 | 10 | 12 | 23 |
| | Quadratic | 47 | 17 | 11 | 6 | 12 | 10 | 1 | 1 | 2 |
| A75 | Linear | 31 | 12 | 6 | 8 | 19 | 18 | 9 | 2 | 11 |
| | Quadratic | 54 | 16 | 12 | 6 | 12 | 5 | 0 | 0 | 0 |
| K75 | Linear | 36 | 9 | 8 | 9 | 17 | 12 | 12 | 2 | 14 |
| | Quadratic | 48 | 17 | 10 | 3 | 16 | 9 | 2 | 0 | 2 |
| Combined | Linear | 40 | 7 | 7 | 4 | 26 | 16 | 4 | 1 | 5 |
| | Quadratic | 87 | 11 | 3 | 2 | 1 | 1 | 0 | 0 | 0 |

[a]Number of mixtures with F values significant at the 5% level.

Table 29. Frequency distributions for F values for linear and quadratic responses of grain yield to variation in frequency of mixture components in 105 mixtures within and across environments

| Environ-ment | Poly-nomial | Class interval | | | | | | | | No. sig.[a] |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.00-0.29 | 0.30-0.59 | 0.60-0.89 | 0.90-1.19 | 1.20-1.99 | 2.00-3.99 | 4.00-6.99 | > 7.00 | |
| A74 | Linear | 35 | 11 | 12 | 9 | 15 | 11 | 8 | 4 | 12 |
| | Quadratic | 55 | 14 | 11 | 10 | 12 | 3 | 0 | 0 | 0 |
| K74 | Linear | 27 | 11 | 13 | 4 | 5 | 15 | 12 | 18 | 30 |
| | Quadratic | 58 | 15 | 10 | 10 | 9 | 2 | 1 | 0 | 1 |
| A75 | Linear | 22 | 6 | 12 | 6 | 20 | 17 | 10 | 12 | 24 |
| | Quadratic | 56 | 19 | 11 | 7 | 5 | 6 | 1 | 0 | 1 |
| K75 | Linear | 38 | 17 | 12 | 3 | 17 | 12 | 5 | 1 | 7 |
| | Quadratic | 52 | 14 | 12 | 4 | 10 | 11 | 2 | 0 | 3 |
| Combined | Linear | 48 | 12 | 7 | 4 | 7 | 21 | 6 | 0 | 7 |
| | Quadratic | 89 | 14 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |

[a]Number of mixtures with F values significant at the 5% level.

mixtures tended to interact additively. This agrees with results from the diallel analyses (Tables 7, 8, and 9) where GMA (or additive) effects were significant but SMA (or non-additive) effects were nonsignificant.

Experiment 2 - Test Mixtures

Mean squares from the combined analyses of variance for straw and grain yields from Experiment 2 are given in Table 30. Note that significant ($P \leq 0.01$) differences existed among lines and among testers but that the line x tester interaction was nonsignificant for both traits. Generally, interactions of lines and/or testers with locations and years were non-significant. These results indicate that differences among the lines in test mixtures were independent of the tester used.

The product moment correlations between line means in 1:1 mixtures and in test mixtures were 0.82** for straw yield and 0.86** for grain yield. The correlations between line means in pure stand and in test mixtures were 0.77** for straw yield and 0.91** for grain yield. Data averaged over locations and years were used to obtain these correlations. Thus the performance of lines in test mixtures was a good indicator of the performance of 1:1 mixtures of the lines. However, the performance of lines in pure stand was also a good indicator of their performance in 1:1 mixtures ($r = 0.91$** for straw yield and $r = 0.91$** for grain yield), so that the use of

Table 30. Mean squares from combined analyses of variance for straw and grain yields of test mixtures evaluated across two locations and two years

| Source | Degrees of freedom | Mean squares Straw | Grain |
|---|---|---|---|
| Year | 1 | 334154 | 120831 |
| Location | 1 | 150314 | 4586 |
| Year x location | 1 | 4825 | 6163 |
| Rep/yr, loc | 16 | 1020 | 487 |
| Lines | 27 | 192** | 126** |
| Testers | 5 | 2968** | 1869** |
| Lines x testers | 135 | 43 | 28 |
| Lines x yrs | 27 | 65 | 51 |
| Lines x loc | 27 | 51 | 23 |
| Lines x yrs x loc | 27 | 54 | 38** |
| Testers x yrs | 5 | 215** | 31 |
| Testers x loc | 5 | 54 | 33 |
| Testers x yrs x loc | 5 | 19 | 26 |
| Lines x testers x yrs | 135 | 46 | 26 |
| Lines x testers x loc | 135 | 44 | 20 |
| Lines x testers x yrs x loc | 135 | 40 | 23 |
| Residual | 2672 | 44 | 22 |
| Coefficient of variation (%) | | 16.2 | 14.3 |

**Significant at 1% level.

test mixtures to identify lines which combine to form high yielding mixtures is not needed.

# DISCUSSION

Genotype x environmental interactions for 1:1, 1:1a, 1:3, and 3:1 mixture sets were considerably smaller than those for oat lines grown in pure stands, particularly for straw yield. Several other workers (Jensen, 1952; Allard, 1961; Pfahler, 1965) found similar results. Clay and Allard (1969), however, found that mixtures of barley varieties were less stable than the varieties grown in pure stand. Marshall and Brown (1973) concluded that even in the absence of intergenotypic interactions a mixture would be more stable than its components provided at least one component line responded differentially to at least one environment. The mixtures would become more stable relative to their component lines as the genotype x environmental interaction of the component lines increased. Hence, in my experiment, component lines apparently responded differentially in monoculture in some environments so that mixtures had smaller fluctuations over locations and years than did the lines.

My results indicated that general mixing ability was a very important source of variation but that specific mixing ability was not for either grain or straw yield in any mixture set. Similar results were obtained by Jensen and Federer (1965) for a four-line mixture diallel experiment in wheat. However, Frey and Maldonado (1967) concluded that the yield advantage of a mixture of oat cultivars was due to the specific combination of cultivars that it contained and not to a general effect of one cultivar. Their environmental variability was limited, however, to a single factor, date of planting.

Most mixtures in my experiment were not significantly different from the midcomponent for either straw yield or grain yield in any of the three mixture sets. A significant number of mixtures differed significantly ($P \leq 0.10$) from the midcomponent mean (e.g., 73 and 54 out of 378 1:1 mixtures for straw and grain yield, respectively). There was a trend for more mixtures to yield above the midcomponent than below the midcomponent. This agrees with Trenbath (1974) who found that of 344 mixtures he reviewed, 60.2% were above the midcomponent and 39.8% were below. In my experiment, some mixtures exceeded their midcomponents--an overcompensatory response (Schutz and Brim, 1967; Schutz et al., 1968)--by up to 17% for straw yield and 13% for grain yield when averaged over environments. These mixture advantages were larger than the 3-9% advantages reported by other workers (Jensen, 1952; Gustafsson, 1953; Sammeta, 1967; Clay and Allard, 1969) for grain yield in cereals. Fewer than 5% of my mixtures significantly ($P \leq 0.10$) yielded above the component with the highest yield in pure stand or below the component with the lowest yield in pure stand. Probably the small proportion of transgressive mixtures occurred due to chance. Donald (1963) and Trenbath (1974) also concluded that the yields of mixtures usually were between the components' monoculture yields.

My experiments were not designed to study mechanisms that may cause a component's yield in mixture to differ from its yield in pure stand, or the mixture to exceed the mid or high component yield. However, I shall discuss briefly some mechanisms which have been studied by other workers and relate these to my results.

The environmental resources for which plants compete are principally light, water, and soil-nutrient supplies (Donald, 1963). When yields of individual components in a mixture are examined, the general conclusion about competition for light is that the component with its leaf area higher in the canopy is at an advantage (Iwaki, 1959; Williams, 1963; Snaydon, 1971). If the taller component has a greater leaf area, its advantage will be correspondingly greater (Iwaki, 1959). Donald (1958) and Snaydon (1971) showed that competition for soil nutrients produced large effects on component yields in mixtures. Lee (1960) showed that the competitive advantage of Atlas over Vaughn barley was probably due to the earlier and more dense, though somewhat shallower, root development of Atlas. This may have given Atlas a greater capacity to exploit water and nutrients in the surface soil when the two varieties were grown in competition. Donald (1958) suggested that both root and shoot competition occur in agricultural crops. Using ecotypes of white clover, Snaydon (1971) confirmed this and showed that root competition had a greater effect, and probably began earlier, than shoot competition. However, his experiments were conducted in pots so the effect of root competition may have been overestimated.

Let the competitive ability of a genotype be its ability to increase its yield in mixture over its yield in monoculture, or its ability to predominate in a mixture after several generations. Now consider whether the competitive ability of mixture components is related to the performance of the mixture as a whole. If there is strong competition between components for some environmental resource (e.g., light, water, or nutrients), then the yield increment of one component in a mixture may be offset by the yield decrement of the other component so that the mixture yield will not differ from the midcomponent yield. Such complementary responses were observed by Eberhart et al. (1964) in mixtures of maize single crosses, by Early and Qualset (1971) in barley mixtures, by Khalifa and Qualset (1974) in a wheat mixture, and by Trenbath (1975) in interspecific Avena mixtures. Complementary responses may have occurred in my experiment for mixtures which were not significantly different from the midcomponent. If the yield increment (decrement) of one component was slightly greater than the yield decrement (increment) of the other component in mixture, then the mixture yield would be greater than (less than) the midcomponent but less than the high component (greater than the low component) yield. Thus, competition for the same environmental resources probably would result in mixture yields within the range of the component yields.

Donald (1963) concluded that there was no substantial evidence to show that a mixture of two genotypes could fix more carbon (and hence yield more) than the more productive of the two genotypes grown in monoculture. However, if there was no competition between mixture components for the same environmental resource so that each component used some part(s) of the environment that the other could not utilize, then the mixture yield could exceed the high component monoculture yield because intragenotypic competition would be less in mixtures. In the shoot environment, one component probably would always infringe on the light environment of the other component (although if the light intensity was greater than that required for saturation of the photosynthetic process, competition for light may be less than expected). Differences in environmental niches occupied are more likely to occur in the root zone. An _Avena strigosa_ - _A. fatua_ mixture studied by Trenbath (1975) yielded above the high monoculture component (_A. fatua_) by 12.3% for panicle weight and 12.7% for straw weight (per plant basis) on deep soil. _A. fatua_ had a deep root system whereas _A. strigosa_ had a shallow one. Where soil depth did not allow stratification of the root systems, the yield of this mixture was within the range of the components' monoculture yields.

From these considerations I infer that, in my experiments, components of mixtures generally occupied similar environmental niches, and therefore were competing for the same environmental resources.

Straw and grain yields were reduced 12-16 q/ha and 9-10 q/ha, respectively, by the late planting in 1975 (May 1-5) compared with the normal planting in 1974 (April 1-3). However, the range in relative mixture values was similar in the two years; for example, 85-120% and 71-125% in A75 and K75, respectively, compared with 77-120% and 76-123% in A74 and K74, respectively, for RMV relative to the midcomponent for grain yield (Table 13). Also the mean mid RMV's were 100% in A74 and K74 and 100% and 101% in A75 and K75, respectively, for grain yield. Thus there was no evidence in my results that mixtures performed relatively better in suboptimum environments caused by delayed planting. This is in contrast to the conclusions of Frey and Maldonado (1967).

My results indicated that straw or grain yield differentials between mixtures and their components grown in monocultures generally were not repeatable across environments. There have been no reported experiments that have examined the repeatability of the relative performance of mixtures and monocultures. Considerably more work has been done on the heritability of competitive ability (as defined earlier) of individual components in mixtures. Oka (1960, cited by Donald, 1963) crossed Japonica and Indica type rices and the parental lines, the $F_2$ population, and the $F_3$ lines were tested for competitive ability against a standard variety. The heritability of competitive ability was 0.12 for panicle number and 0.03 for plant weight. Thus, when examined as a genetic character competitive ability had a very low heritability. Sakai and Gotoh (1955) found that competitive ability was not associated with height, maturity, seed size, plant habit, heading habit, or grain yield in barley. Thus, Sakai (1955) argued that competitive ability should be accepted as a genetic character *per se*. However, Donald (1963) indicated that to consider competitive ability as a genetic character "is a generalization of doubtful value" because of the numerous plant characters that may be involved in competition for light, water, or various nutrients. If competitive ability is the result of the complex interaction of several plant characters, then as the environment changed, the nature of this interaction could change also, so that competitive ability, and the relative performance of mixtures and their component monocultures, may have a low heritability or repeatability over environments. Therefore, the low repeatabilities of the relative yields of mixtures and their midcomponents in my study (0-10.3%) may be the result of genotype x environmental interaction for the complex of plant characters that determine competition for environmental resources.

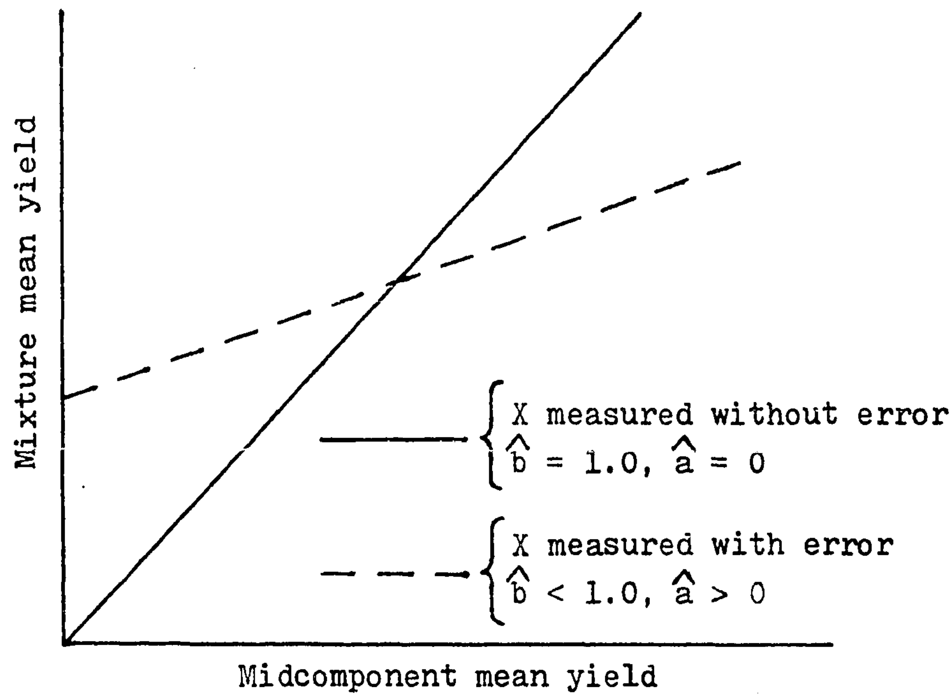
Mixtures tended to be lower yielding than their midcomponents at low yield levels and higher yielding than their midcomponents at high yield levels. This is in contrast to the conclusions of several other workers (Roy, 1960; Jensen, 1965; Byth and Caldwell, 1970; Gedge, 1974). For example, Jensen

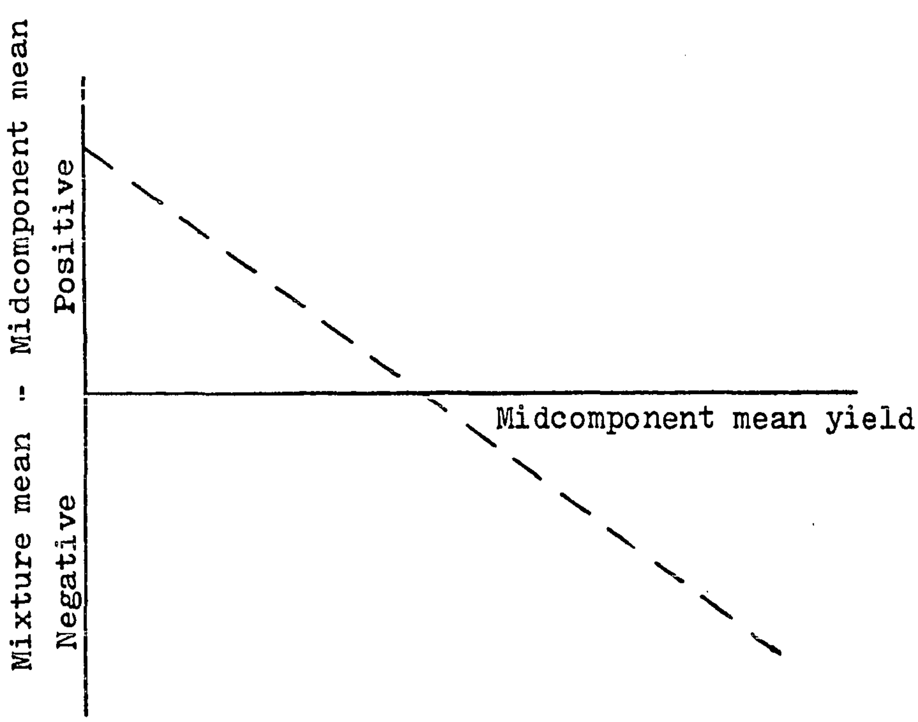
(1965) found that the yield difference between a mixture and the mean of its components increased positively as the midcomponent yield level decreased. Byth and Caldwell (1970) and Gedge (1974) reported that the yield deviation of $F_2$ derived parental lines (or blends of $F_5$ lines derived from each $F_2$ parental line) from the mean of their $F_5$ derived lines increased as the yield level of the $F_5$ lines decreased. Thus these workers have implied that a negative relationship exists between the yield deviation of mixtures from their midcomponents and the midcomponent yield level. However, this inference is incorrect because measurement errors associated with the midcomponent mean yield estimate were not considered (Snedecor and Cochran, 1967).

Assume that the "true difference" between the mixture mean yield and the midcomponent mean yield is zero at all yield levels. Then if the midcomponent mean yields were determined without error, the regression of mixture mean on midcomponent mean would pass through the origin with a slope of 1.0 (Figure 7). However, the midcomponent mean yields always would be determined with error so that the regression would not pass through the origin and would have a slope less than 1.0 (Figure 7). Clay and Allard (1969) incorrectly indicated that the regression would have a slope of 1.0 if no interaction occurred between components. Thus, the simple arithmetic difference between the observed mixture mean yield

Figure 7. Theoretical regressions of mixture mean yield (Y) on midcomponent mean yield (X) with and without measurement errors associated with X; for both regressions it is assumed that the "true" difference between Y and X is zero at all values of X

Figure 8. Theoretical regression of difference between mixture mean yield and midcomponent mean yield on midcomponent mean yield (X) when the latter is measured with error; it is assumed that the "true" difference is zero at all values of X


Mixture mean yield
X measured without error
$\hat{b}$ = 1.0, $\hat{a}$ = 0
X measured with error
$\hat{b}$ < 1.0, $\hat{a}$ > 0
Midcomponent mean yield


Mixture mean - Midcomponent mean
Positive
Negative
Midcomponent mean yield

and the observed midcomponent mean yield would be positive at low midcomponent mean yield levels and negative at high midcomponent mean yield levels (Figure 8), even though I assumed the "true difference" was zero at all yield levels. In other words, the expectation of the correlation between the difference (mixture mean yield - midcomponent mean yield) and the midcomponent mean yield is not zero but is some negative value, the magnitude of which depends on the size of the genotypic variance among lines and measurement errors associated with the observed component means.

Mixtures of the random lines derived from a bulk population propagated over several generations exceeded the midcomponent means by a larger amount than did mixtures of released cultivars. Similar results were obtained by Allard and Adams (1969). However, the highest yielding mixtures (Table 27) were formed from lines from the bulk population as well as from some of the cultivars released for high performance in monoculture. For either straw or grain yield the highest yielding mixtures were no better than either their highest yielding component or the highest yielding cultivar or line in monoculture. My results indicate, therefore, that the use of mixtures of oat cultivars or lines to obtain a yield advantage over monocultures is not justified. Griffing (1967) suggested that group selection--where a group of genotypes is accepted or rejected on the basis of the group mean--is necessary to take advantage of intergenotypic interactions.

If the number of individuals in a group is relatively small, then this strategy may produce high yielding heterogeneous groups where a yield boost due to the heterogeneity has been incorporated by the selection method.

## SUMMARY

Relative straw and grain yields of mixtures and monocultures of 28 oat cultivars and lines were studied in two locations for two years. The conclusions reached were:

1. Genotype x environmental interactions for mixtures were considerably smaller than those for oat lines grown in pure stands, particularly for straw yield.
2. General mixing ability was a very important source of variation but specific mixing ability was not significant for either straw or grain yield, i.e., the yield of an individual mixture did not deviate significantly from the mean yield of all mixtures containing either of its components.
3. Most mixtures were not significantly different from the midcomponent for either straw or grain yield. There was a trend for more mixtures to yield above than below the midcomponent. The small proportion of mixtures that yielded above the component with the highest yield in pure stand or below the component with the lowest yield in pure stand probably occurred by chance. Yield increments of mixtures above their midcompoments were larger for mixtures of random lines than for mixtures of cultivars.
4. Straw or grain yield differentials between mixtures and their components grown in monoculture generally

were not repeatable across environments.

5. There was a significant linear response but no quadratic response to changing component frequency in some mixtures, so that components of mixtures tended to interact additively.
6. The performance of lines in pure stand was a good indicator of their performance in mixtures, so the use of test mixtures to identify lines which combine to form high yielding mixtures is not needed.
7. The yield advantage of mixtures over their midcomponent means increased as the yield level increased, but the highest yielding mixtures were no better than either their highest yielding component or the highest yielding line in test. Therefore, the use of mixtures of oat cultivars or lines to obtain a yield advantage over monocultures is not justified.

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APPENDIX

Table 31. Frequency distribution of relative mixture values (RMV)[a] for straw yield and grain yield in 1:3 mixtures averaged across environments

| Class midpoint | Straw yield | | | Grain yield | | |
|---|---|---|---|---|---|---|
| | Low | Mid | High | Low | Mid | High |
| 85.5 | | | 1 | | | 1 |
| 87.5 | | | 5 | | | 9 |
| 89.5 | | 1 | 7 | | | 4 |
| 91.5 | 2 | 2 | 11 | | 1 | 9 |
| 93.5 | 0 | 4 | 14 | 1 | 5 | 10 |
| 95.5 | 6 | 17 | 19 | 1 | 10 | 18 |
| 97.5 | 11 | 20 | 11 | 21 | 25 | 20 |
| 99.5 | 13 | 21 | 17 | 9 | 22 | 16 |
| 101.5 | 8 | 16 | 10 | 23 | 18 | 10 |
| 103.5 | 15 | 13 | 6 | 13 | 18 | 8 |
| 105.5 | 9 | 8 | 3 | 16 | 6 | |
| 107.5 | 14 | 2 | 0 | 11 | | |
| 109.5 | 6 | 1 | 1 | 2 | | |
| 111.5 | 9 | | | 4 | | |
| 113.5 | 3 | | | 2 | | |
| 115.5 | 4 | | | 2 | | |
| 117.5 | 1 | | | | | |
| 119.5 | 4 | | | | | |
| Critical values[b] | | | | | | |
| P = .10 | 93<br>107 | 93<br>107 | 93<br>107 | 94<br>106 | 94<br>106 | 94<br>106 |
| P = .05 | 92<br>108 | 92<br>108 | 92<br>108 | 93<br>107 | 93<br>107 | 93<br>107 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

[b]For two-tailed t test.

Table 32. Frequency distribution of relative mixture values (RMV)[a] for straw yield in 1:3 mixtures within environments

| Class midpoint | Ames 1974 | | | Kanawha 1974 | | | Ames 1975 | | | Kanawha 1975 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low | Mid | High | Low | Mid | High | Low | Mid | High | Low | Mid | High |
| 63 | | | | | | | | | | | | 1 |
| 68 | | | | | | | | | | | | 2 |
| 73 | | | | | | 1 | | | | | 1 | 3 |
| 78 | | | | | | 4 | | | 2 | 2 | 3 | 4 |
| 83 | 2 | 2 | 7 | 1 | 1 | 10 | | 2 | 7 | 1 | 7 | 18 |
| 88 | 3 | 6 | 12 | 1 | 6 | 9 | 7 | 11 | 20 | 10 | 14 | 18 |
| 93 | 4 | 20 | 33 | 14 | 25 | 34 | 8 | 19 | 26 | 8 | 16 | 15 |
| 98 | 19 | 36 | 21 | 22 | 27 | 19 | 27 | 34 | 28 | 16 | 16 | 16 |
| 103 | 22 | 17 | 12 | 14 | 19 | 14 | 22 | 22 | 15 | 20 | 20 | 14 |
| 108 | 19 | 12 | 15 | 22 | 18 | 9 | 18 | 12 | 5 | 10 | 12 | 6 |
| 113 | 11 | 9 | 4 | 9 | 6 | 4 | 12 | 3 | 1 | 13 | 8 | 6 |
| 118 | 15 | 3 | 1 | 13 | 2 | 1 | 4 | 2 | 1 | 9 | 6 | 1 |
| 123 | 7 | | | 6 | 1 | | 5 | | | 13 | 1 | 1 |
| 128 | 2 | | | 1 | | | 2 | | | 2 | 1 | |
| 133 | 1 | | | 2 | | | | | | 1 | | |
| Critical values[b] | | | | | | | | | | | | |
| P = .10 | 87 | 88 | 87 | 88 | 88 | 88 | 87 | 88 | 87 | 83 | 83 | 83 |
| | 113 | 112 | 113 | 112 | 112 | 112 | 113 | 112 | 113 | 117 | 117 | 117 |
| P = .05 | 85 | 86 | 85 | 85 | 86 | 85 | 85 | 85 | 85 | 79 | 80 | 79 |
| | 115 | 114 | 115 | 115 | 114 | 115 | 115 | 115 | 115 | 121 | 120 | 121 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

[b]For two-tailed t test.

Table 33. Frequency distribution of relative mixture values (RMV)[a] for grain yield in 1:3 mixtures within environments

| Class midpoint | Ames 1974 | | | Kanawha 1974 | | | Ames 1975 | | | Kanawha 1975 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low | Mid | High | Low | Mid | High | Low | Mid | High | Low | Mid | High |
| 73 | | | | | | 2 | | | | | | 3 |
| 78 | | | 1 | | | 3 | | | 1 | | 1 | 2 |
| 83 | | 1 | 5 | | | 11 | | | 5 | 4 | 7 | 9 |
| 88 | 3 | 6 | 21 | 3 | 8 | 16 | 3 | 5 | 20 | 9 | 9 | 19 |
| 93 | 13 | 22 | 18 | 8 | 16 | 25 | 7 | 23 | 36 | 7 | 15 | 28 |
| 98 | 21 | 27 | 29 | 19 | 32 | 24 | 27 | 34 | 22 | 22 | 26 | 18 |
| 103 | 25 | 26 | 17 | 31 | 28 | 14 | 20 | 25 | 14 | 23 | 28 | 15 |
| 108 | 24 | 18 | 12 | 20 | 14 | 9 | 23 | 10 | 7 | 22 | 8 | 8 |
| 113 | 12 | 4 | 2 | 12 | 6 | 1 | 14 | 8 | | 8 | 7 | 1 |
| 118 | 5 | 1 | | 9 | 0 | | 6 | | | 7 | 2 | 1 |
| 123 | 1 | | | 1 | 1 | | 3 | | | 1 | 0 | 1 |
| 128 | 1 | | | 2 | | | 0 | | | 2 | 2 | |
| 133 | | | | | | | 1 | | | | | |
| 138 | | | | | | | 0 | | | | | |
| 143 | | | | | | | 1 | | | | | |
| Critical values[b] | | | | | | | | | | | | |
| P = .10 | 87 | 88 | 87 | 89 | 89 | 89 | 89 | 89 | 89 | 86 | 86 | 86 |
| | 113 | 112 | 113 | 111 | 111 | 111 | 111 | 111 | 111 | 114 | 114 | 114 |
| P = .05 | 85 | 85 | 85 | 87 | 87 | 87 | 86 | 87 | 86 | 83 | 84 | 83 |
| | 115 | 115 | 115 | 113 | 113 | 113 | 114 | 113 | 114 | 117 | 116 | 117 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

[b]For two-tailed t test.

Table 34. Frequency distribution of relative mixture values (RMV)[a] for straw yield and grain yield in 3:1 mixtures averaged across environments

| Class midpoint | Straw yield | | | Grain yield | | |
|---|---|---|---|---|---|---|
| | Low | Mid | High | Low | Mid | High |
| 81.5 | | | 2 | | | 1 |
| 83.5 | | | 1 | | | 1 |
| 85.5 | | | 2 | | | 5 |
| 87.5 | | | 5 | | | 4 |
| 89.5 | | | 12 | | 1 | 14 |
| 91.5 | 2 | 5 | 12 | 1 | 4 | 10 |
| 93.5 | 2 | 7 | 17 | 4 | 7 | 9 |
| 95.5 | 6 | 17 | 14 | 4 | 14 | 26 |
| 97.5 | 10 | 18 | 13 | 9 | 20 | 14 |
| 99.5 | 14 | 14 | 11 | 18 | 17 | 9 |
| 101.5 | 16 | 18 | 8 | 14 | 19 | 7 |
| 103.5 | 12 | 11 | 3 | 13 | 13 | 3 |
| 105.5 | 13 | 6 | 1 | 16 | 6 | 2 |
| 107.5 | 7 | 4 | 2 | 8 | 3 | |
| 109.5 | 9 | 4 | 1 | 8 | 1 | |
| 111.5 | 9 | 1 | 1 | 4 | | |
| 113.5 | 3 | | | 2 | | |
| 115.5 | 1 | | | 2 | | |
| 117.5 | 0 | | | 1 | | |
| 119.5 | 1 | | | 1 | | |
| Critical values[b] | | | | | | |
| P = .10 | 93<br>107 | 93<br>107 | 93<br>107 | 94<br>106 | 94<br>106 | 94<br>106 |
| P = .05 | 92<br>108 | 92<br>108 | 92<br>108 | 92<br>108 | 93<br>107 | 92<br>108 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

[b]For two-tailed t test.

Table 35. Frequency distribution of relative mixture values (RMV)[a] for straw yield in 3:1 mixtures within environments

| Class midpoint | Ames 1974 | | | Kanawha 1974 | | | Ames 1975 | | | Kanawha 1975 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low | Mid | High | Low | Mid | High | Low | Mid | High | Low | Mid | High |
| 68 | | | | | | 1 | | | | | | |
| 73 | | | 1 | | 1 | 2 | | | | | | 2 |
| 78 | | 1 | 6 | | 0 | 7 | | | | | 5 | 10 |
| 83 | 1 | 0 | 6 | 3 | 4 | 8 | | | 10 | 4 | 5 | 12 |
| 88 | 4 | 13 | 26 | 4 | 12 | 18 | 7 | 12 | 21 | 4 | 11 | 13 |
| 93 | 12 | 18 | 27 | 10 | 18 | 22 | 12 | 21 | 26 | 8 | 18 | 22 |
| 98 | 20 | 26 | 18 | 12 | 26 | 20 | 20 | 27 | 21 | 14 | 14 | 14 |
| 103 | 25 | 26 | 12 | 35 | 25 | 19 | 22 | 19 | 16 | 20 | 16 | 13 |
| 108 | 21 | 11 | 5 | 19 | 10 | 3 | 14 | 17 | 9 | 18 | 16 | 9 |
| 113 | 18 | 9 | 4 | 13 | 7 | 4 | 18 | 5 | 0 | 13 | 8 | 2 |
| 118 | 3 | 1 | | 8 | 2 | 1 | 5 | 2 | 2 | 8 | 4 | 4 |
| 123 | 1 | | | 0 | | | 5 | 2 | | 6 | 3 | 1 |
| 128 | | | | 1 | | | 2 | | | 4 | 2 | 1 |
| 133 | | | | | | | | | | 1 | 1 | 1 |
| 138 | | | | | | | | | | 0 | 1 | 0 |
| 143 | | | | | | | | | | 2 | 0 | 0 |
| 148 | | | | | | | | | | 2 | 0 | 1 |
| 153 | | | | | | | | | | 0 | 1 | |
| ... | | | | | | | | | | ... | | |
| 168 | | | | | | | | | | 1 | | |
| Critical values[b] | | | | | | | | | | | | |
| P = .10 | 87 | 88 | 87 | 88 | 89 | 88 | 87 | 88 | 87 | 81 | 82 | 81 |
| | 113 | 112 | 113 | 112 | 111 | 112 | 113 | 112 | 113 | 119 | 118 | 119 |
| P = .05 | 85 | 86 | 85 | 86 | 87 | 86 | 85 | 86 | 85 | 77 | 78 | 77 |
| | 115 | 114 | 115 | 114 | 113 | 114 | 115 | 114 | 115 | 123 | 122 | 123 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

[b]For two-tailed t test.

Table 36. Frequency distribution of relative mixture values (RMV)[a] for grain yield in 3:1 mixtures within environments

| Class midpoint | Ames 1974 | | | Kanawha 1974 | | | Ames 1975 | | | Kanawha 1975 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low | Mid | High | Low | Mid | High | Low | Mid | High | Low | Mid | High |
| 73 | | | 1 | | | 2 | | | | | | |
| 78 | | | 5 | | 2 | 2 | | | | 1 | 1 | 2 |
| 83 | 2 | 5 | 6 | 2 | 3 | 10 | | 1 | 6 | 2 | 4 | 8 |
| 88 | 4 | 7 | 9 | 3 | 9 | 18 | 1 | 7 | 20 | 1 | 12 | 22 |
| 93 | 10 | 13 | 30 | 9 | 25 | 26 | 11 | 23 | 31 | 10 | 18 | 13 |
| 98 | 23 | 32 | 23 | 20 | 29 | 25 | 24 | 28 | 24 | 17 | 17 | 20 |
| 103 | 27 | 28 | 24 | 21 | 18 | 12 | 20 | 22 | 18 | 18 | 20 | 23 |
| 108 | 22 | 14 | 4 | 21 | 14 | 8 | 18 | 19 | 6 | 22 | 20 | 8 |
| 113 | 11 | 5 | 3 | 16 | 5 | 2 | 18 | 5 | | 20 | 4 | 2 |
| 118 | 4 | 1 | | 8 | | | 12 | | | 7 | 5 | 5 |
| 123 | 1 | | | 2 | | | 1 | | | 3 | 3 | 1 |
| 128 | 0 | | | 3 | | | | | | 3 | 0 | 0 |
| 133 | 1 | | | | | | | | | 0 | 0 | 1 |
| 138 | | | | | | | | | | 1 | 1 | |
| Critical values[b] | | | | | | | | | | | | |
| P = .10 | 87 | 88 | 87 | 88 | 89 | 88 | 89 | 90 | 89 | 85 | 86 | 85 |
| | 113 | 112 | 113 | 112 | 111 | 112 | 111 | 110 | 111 | 115 | 114 | 115 |
| P = .05 | 85 | 85 | 85 | 86 | 87 | 85 | 87 | 88 | 87 | 82 | 83 | 82 |
| | 115 | 115 | 115 | 114 | 113 | 114 | 113 | 112 | 113 | 118 | 117 | 118 |

[a]RMV = mixture yield relative to low, mid, or high component pure stand yield expressed as a percentage.

[b]For two-tailed t test.